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E. P. Scheide, J. J. Filliben, and J. K. Taylor

National Bureau of Standards
Department of Commerce
Washington, D.C. 20234

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Final Report

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The Environmental Protection Agency
Office of Toxic Substances
Washington, D.C.

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This report describes the development of a plan to comprehensively survey the occurrence of potentially toxic substances in a defined geographical area and its application to the determination of the concentration levels of mercury, lead, and cadmium in various aspects of the environment in the Washington, D.C. area. It describes the basic philosophy of such a survey, the development of a sampling plan, and the identification of analytical methods adequate to obtain the required measurements. Methods of data reduction using the NBS computer are also described. The data are presented in tables and unique computer-generated plots which show the overall concentration profiles and spots of elevated concentration levels. No significantly hazardous conditions were found to exist. The approach followed and the data reduction techniques developed should be useful to surveys of these elements in other areas and also for surveys of ubiquitous hazardous materials in general.

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The Occurrence of Mercury, Lead and Cadmium in the Washington, D.C. Area

E.P. Scheide, J.J. Filliben, and J.K. Taylor

ABSTRACT

This report describes the development of a plan to comprehensively survey the occurrence of potentially toxic substances in a defined geographical area and its application to the determination of the concentration levels of mercury, lead, and cadmium in various aspects of the environment in the Washington, D.C. area. It describes the basic philosophy of such a survey, the development of a sampling plan, and the identification of analytical methods adequate to obtain the required measurements. Methods of data reduction using the NBS computer are also described. The data are presented in tables and unique computer-generated plots which show the overall concentration profiles and spots of elevated concentration levels. Based on the current study, no significantly hazardous conditions were found to exist. The approach followed and the data reduction techniques developed should be useful to surveys of these elements in other areas and also for surveys of ubiquitous hazardous materials in general.

KEY WORDS

Environmental surveys; toxic materials, lead; cadmium; mercury; environmental data; computer techniques for environmental data.

1. INTRODUCTION

The control of toxic substances demands a number of approaches and often requires a variety of analytical measurements. For those substances resulting from a limited number of sources, control at the source is the obvious approach and specific measurements at the source may be all that is required. For ubiquitous substances, the control process is ill-defined and may be multi-faceted and the analytical data may need to be derived from a variety of measurements over an extended period of time.

The distribution of heavy metals, particularly mercury, lead, and cadmium, is an example of the latter type. Low levels can be found almost everywhere and the distribution is heterogeneous and random. Accordingly, analytical data on a few samples can be meaningless or misleading, so that many samples may need to be examined over a considerable time period. Furthermore, such measurements must be made over the full range of the environment, e.g., air, water, sewer, soil, sediments - to fully interpret any environmental threat.

Although many measurements have been made of heavy metals in the environment, relatively few have been made in comprehensive, planned programs to assess potential environmental impacts. Because of the increasing interest in these and other ubiquitous substances, both from the standpoint of present distribution and future trends, the present project was sponsored by the EPA Office of Toxic Substances. The objective was to develop and demonstrate an analytical methodology for ascertaining the distribution of specific toxic substances in a defined metropolitan area. The techniques and rational developed are believed to be applicable to the accumulation of data for mass-balance evaluation of a variety of toxic substances.

This report discusses the philosophy for development of an area-wide environmental survey, the methodology necessary to obtain the required data, and the interpretation of the results. The techniques were originally developed for measurement of mercury but the scope of the project was later broadened to include lead and cadmium. However, the general approach, with suitable modifications of the measurement methodology should be applicable to surveys of a wide variety of hazardous substances ubiquitously distributed in the environment.

2. APPROACH

The intent of the present project was to develop and demonstrate methodology necessary for a comprehensive overall survey of a well-defined geographical area. The area designated for study was that within the municipal boundaries of the District of Columbia. A comprehensive understanding of any specific toxic substance requires a knowledge of the overall distribution and the identification of any areas of elevated level. Such data needs to be taken over a period of time to identify trends and also to minimize the chance of false conclusions - either positive or negative - resulting from large random errors of sampling and/or measurement. A knowledge of the pathways of entrance and

egress of specific substances is needed to provide guidance in selection of measurement situations and locations as well as to aid in prediction of possible environmental problems. Washington, D.C. is essentially a light industrial area, with government operations as a major source of employment. A survey of possible large industrial users and/or producers of the three metals was undertaken but none was found within the area. If present, each would have to be considered as a point source and suitable measurements would have been made. The only potential point sources within the area appeared to be two electric power generation plants and facilities concerned with the disposal of solid waste and with sewage treatment.

The drinking water and sewage distribution systems were considered to be primary potential pathways for distribution of heavy metals within the area, as were the natural waterways within the area. The Potomac River forms one boundary of the area and the Anacostia River traverses the area as does Rock Creek. Accordingly, the analysis of river and stream waters and sediments was considered to be an important aspect of the data base.

The Potomac Electric Power Co. has two generation plants in the area. These are oil-fired plants. Sampling sites were selected in the area of the plants to include soil, river water, sediments, and drinking water.

A number of discussions were arranged with engineers responsible for operation and maintenance of the public water system, the sewage system, the waste-water treatment facility, and the solid waste disposal plants not only to obtain detailed information on their operational characteristics but also to facilitate collection of samples for analysis. These discussions provided the basis for construction of the diagrams shown in Figure 1 and Figure 2.

Figure 1 describes the major pathways for water including the fresh water supply and sewage disposal. The city of Washington, D.C. obtains its drinking water from the Potomac River, as do the bordering counties of Prince George's and Montgomery in Maryland. The river also serves as a partial supply of water for neighboring Virginia areas. The Blue Plains sewage treatment plant receives waste-water from D.C., Maryland and Virginia. The sludge is disposed of in Maryland and Virginia for landfill, hence leaves the Washington area. The treated effluent is discharged into the river.

The flow diagram for solid waste disposal is shown in Figure 2. The city is subdivided into 9 service areas for residential disposal. Private haulers pick up solid waste from large sources such as business establishments. Here again, the incinerator ash and/or untreated waste are trucked to landfill areas outside of the District of Columbia.

3. SAMPLING STRATEGY

The area of the District of Columbia amounts to approximately 70 square miles (181 km^2). In addition, there are many miles of sewer and water lines. The rivers and streams flow for some 30 miles through this area. Accordingly, even the measurement of one environmental substance - water - has many problems. It is evident that any sampling and analysis program must be a compromise between what is desirable and what can be done under the constraints of time and funding. Accordingly, such programs must be planned with care to maximize the information output.

From overall considerations of available funding and cost of sampling and analysis, a maximum number of approximately 4000 samples was decided upon. Because potential trouble spots in this case could not be identified in advance, the sampling program needed to be designed to maximize the coverage. Duplicate samples were provided for at selected times and locations, and split samples were also issued to the analytical laboratory to evaluate the measurement process.

A large scale map was used to lay out the area in a grid pattern, with the intention of developing a systematic sampling plan. An immediate conclusion from study of such a scheme is that all areas are not equal from a sampling point of view. For example, a significant part of the area is in parkland and/or covered by water. A relatively few samples of such would appear to be indicative of a wide area.

With respect to soil and dust samples, the former are of course more predominant in the outer city while information from the latter would be expected to be more important in inner city locations.

Another sample constraint is in the taking of air samples. The need to connect equipment to a power source and to protect it from vandalism during relatively long unattended periods dictates that public buildings and/or established air sampling stations be utilized. The latter was the course of action chosen in this case.

River and stream sampling sites were chosen near the banks or on bridges so that samples could be obtained

without the use of watercraft. Such samples have the advantage that they are more representative of the environmental impact of the population as compared with mid-stream samples. Sediment samples were collected at the same location as those from the body of water.

Samples of waste-water were taken from sewers with access by means of man-holes. Both trunk lines and branch lines were sampled. A practical problem was encountered, in that man-holes are most often located at street intersections and their access may impose traffic impediment problems. The cooperation of the Bureau of Waste, Water and Sewer Services minimized this problem.

In any event, the exact sampling site cannot be selected from a map but needs to be identified in the course of personal inspection of sampling localities. The course of action followed was as follows: The person developing the sampling plan and the one expected to take samples inspected prospective sites together and the actual site was established by mutual agreement. The site location was then described and entered into the sampling protocol.

Waste-water samples and sludge samples were taken at the Blue Plains Waste-Water Treatment Plant. There is no problem in obtaining samples from almost any location in such a plant, but the cooperation of operating personnel is necessary.

The full description of the sampling sites was incorporated into the sampling protocol and is given in Appendix I. Air sampling stations are listed in IA and indicated on Map 1. Sewer sites are listed in IB and indicated on Map 2. All other sampling sites are listed in IC and indicated on Map 3. Each of the sampling sites was assigned a permanent number. Furthermore, they were identified by coordinates (used for data processing) and were given a characteristic name.

The District of Columbia was originally laid out as a square with sides equal to 10 miles in length. The corners of the square were precisely oriented to the four points of the compass. The land area was taken from the states of Maryland and Virginia, with about two-thirds from the former. The Potomac River crosses the area, entering approximately in the middle of the northwest boundary line and exiting at the southern apex of the area. The area to the west of the Potomac River was returned to Virginia (it is now Arlington County) so that the District of Columbia now consists essentially of the area originally belonging to the state of Maryland.

The grid system used for data processing was adapted from one already laid out on a map drawn and published by the Alexandria Drafting Co., Alexandria, VA. The map, based on USGS 1:24,000 quadrangles, contained sub-grid markings on a scale of 1"=2000 ft. These grid lines were arbitrarily marked so that the southern corner of the D.C. had a y coordinate of approximately 0 and the western corner of the original D.C. (now in Virginia) had an x coordinate of 0.

4. MEASUREMENT METHODOLOGY

The Interagency Agreement specified that EPA methods for sampling and analysis should be used insofar as they were applicable to the present problem. The NBS role was to specify the methodology to be used and to critically examine, process, and interpret the analytical data. The actual sampling operations and the analytical measurements were done by personnel of the District of Columbia Department of Environmental Services under the terms of a separate contract with EPA.

NBS developed a protocol which specified the sampling program, the sampling techniques, preparation of samples for analysis, and the analytical methodology. NBS personnel cooperated actively in the sample collection, particularly in the early stages, to identify any problems. NBS personnel also rendered consultation and advisory services in connection with the analytical work and provided quality control samples to evaluate the data. Accordingly, all of the methodology used was approved by NBS as to its adequacy to provide valid data. However, the D.C. Department of Environmental Services had the responsibility for the accuracy of the analytical measurements.

The following sections outline the methodology developed and used. Detailed information on the procedures used will be reported independently by the D.C. Department of Environmental Services under the terms of their contract with EPA.

4.1 Sampling Methodology

4.1.1 Container Cleaning Procedure

The polyethylene sample containers were cleaned each time they were used. The soil containers were scrubbed to remove any particles adhering to the surface, rinsed twice with distilled water and air dryed. The same procedure was followed for the water containers except an acid rinse (dilute HNO_3) was performed before the last distilled water rinse.

4.1.2 Sampling Procedures

Described below are the various types of samples that were taken and the various sampling procedures that were used. The sampling was done only by personnel that had been trained and approved by the NBS project officer.

4.1.2.1 Air Samples

The air samples were taken at established EPA air sampling sites on two consecutive days each month for five months. Also, the air samples were taken on days when there was zero precipitation. The sampler was run for approximately 24 hours with an exact notation of the time ON and OFF recorded in the field notebook. The sampler consisted of three parts: (1) a 0.45 μm filter for particulates, (2) a silver-wool collector for elemental mercury, and (3) a precalibrated pump. The sampling train was assembled in the above order with the silver-wool between the filter and the pump. Protective caps were placed on the filter and silver wool sampler inlet and exit ports at all times when they were not in use.

4.1.2.2 Water Samples

4.1.2.2.1 Sewer Samples

The sewer samples were taken at the designated sewer sites once each month for four months. Duplicate samples were taken. These were monthly grab-samples that were taken using a polyethylene bucket sampler. The sampler was rinsed with the flowing sewer sample twice before the actual sample was taken. One liter of the sewer sample was placed in the sample bottle and immediately 10.0 ml of concentrated reagent grade nitric acid was added as a preservative. The sample and acid were then well mixed. If the sample could not be analyzed within 30 days from the date it was taken, it was discarded.

4.1.2.2.2 River Water

The river water samples were taken in the same manner as the sewer samples, making sure that the sampler was rinsed beforehand and that nitric acid was immediately added to the sample and that they were well mixed. All water samples were to be analyzed within 30 days from sampling.

4.1.2.2.3 Drinking Water

The drinking water samples were obtained directly from the faucet after letting the water run for one minute. As with all the water samples, nitric acid was added as a preservative.

4.1.2.2.4 Stagnant Water

The stagnant water samples are samples that were taken to indicate possible leaching from the water pipes. These samples were taken from the hot water tap without running the water prior to taking the sample.

4.1.2.2.5 Hot Water

Hot water samples were taken from the hot water tap after letting the water run for five minutes. The difference between this sample and the stagnant water sample taken from the same tap should give indications of possible leaching of heavy metals from any galvanized pipe in the water system.

4.1.2.3 Soil Samples

4.1.2.3.1 Topsoil

The topsoil samples consisted of composites taken from the top one inch of the soil. The sample was placed directly into the bottle and was sieved and dryed in the laboratory prior to analysis, following the EPA recommended procedure [1].

4.1.2.3.2 Subsoil

Subsoil samples were taken below 6 inches in depth, using a clean trowel. They were composited and treated the same as topsoil samples.

4.1.2.3.3 Street Dust

Street dust samples consisted of sweepings from the edge of the street. These usually consisted of wind-blown dusts, abraded rubber from automobile tires, and miscellaneous other particles.

4.1.2.3.4 Bottom Sediments

The bottom sediment samples were taken from the bottom of streams and rivers and consisted of the top one inch of the sediment. Some of these locations had "dry" spots at low tide and could be sampled relatively easily, while others had to be sampled near the river bank under water.

4.1.2.3.5 Soil Particle Sizing

In order to increase the reproducibility in the analysis of the soil samples, the samples were sieved prior to analysis. The following procedure was used: first the samples were dried at 60 °C overnight. The dried samples were sieved using a No.

30 sieve. The fraction that passed through the sieve was retained for analysis and the other portion discarded. Both fractions were weighed and this information was recorded in the notebook.

4.1.2.4 Miscellaneous Samples

There were a few other samples that were taken each month that do not fit under any of the headings above. These were sludge and liquid samples taken at various processing points at the Blue Plains Treatment Plant.

The miscellaneous solid samples were treated the same as the soil samples. The liquid samples taken from Blue Plains were treated in the same manner as the previously described water samples.

The solid samples were taken back to the laboratory where they were dried and then sieved using a No. 30 sieve. Just prior to analysis the samples were re-dried and then analyzed using the EPA recommended procedures.

4.1.3 Chain-of-Custody

The following instructions were given to the sampling and analytical groups in order to provide maximum integrity of the samples and analytical data, as far as identity was concerned.

> "Accurate recordkeeping and routing information should be kept on all samples from the time they are collected until they are analyzed. The samples should be taken only by authorized personnel and the field sampling notebook should be kept according to established procedures. Extreme care should be taken in labeling and notebook entries in order to prevent recordkeeping ambiguities. Once the day's sampling is finished, the samples should be delivered to the laboratory and checked in by the analyst-in-charge. A logbook should be kept containing data establishing when samples are checked into the laboratory, by whom, when the samples are analyzed, and by whom. Blanks and controls obtained from NBS should also be entered into this logbook. Certain samples may be checked out by the NBS project officer for splitting in order to obtain duplicate analyses. Records should be kept as to which samples are split and the new sample numbers. The samples should be handled by a minimum number of persons, and it should be easy to locate exactly where each sample is at any point in time. Samples remaining after analysis should be retained until permission for disposal is given by the NBS project officer."

4.2 Analytical Procedures

The samples were prepared and analyzed according to guidelines published in the EPA manual "Methods for Chemical Analysis of Water and Wastes," [1].

4.2.1 Sample Preparation

4.2.1.1 Soil Samples

The soil samples were dried overnight at 60 °C and then mixed thoroughly. A 0.5 gram sample was taken and digested according to the procedure given in the EPA manual on pages 134-138 and pages 118-126 [1].

This digestion procedure is summarized as follows: A weighed portion of the sample is digested in aqua regia for 2 minutes at 95 °C, followed by oxidation with potassium permanganate. Mercury in the digested sample is then measured by the conventional cold vapor atomic absorption technique, while lead and cadmium are analyzed using the graphite furnace atomic absorption technique.

4.2.1.2 Water Samples

The water and sewer samples were also prepared according to the digestion procedure given for the soil samples in order to convert any organo-metallic species into the inorganic form.

4.2.1.3 Air Filters

The air filters were digested in the same manner as the soil samples (see 4.2.1.1).

4.2.2 Analysis

After the samples were digested and filtered, the solutions were split into two fractions; one for mercury analysis, and the other for lead and cadmium analysis.

4.2.2.1 Mercury

The mercury analyses were done by the flameless cold vapor technique described in the EPA manual.

The mercury samples that were collected on silver wool (air samples) were heat desorbed and analyzed according to the procedure described by Long, et al [2].

4.2.2.2 Cadmium and Lead

Cadmium and lead can be analyzed by either flame atomic absorption or the graphite furnace technique depending upon the amount of Cd and Pb in the sample. The graphite furnace technique is much more sensitive than the flame mode. Cadmium and lead were determined according to procedures given in the EPA manual and the Perkin-Elmer manual ["Analytical Methods for Atomic Absorption Spectroscopy Using the HGA Graphite Furnace," (1975)] [3].

4.3 Reporting Results

The samples were compared to standards that were analyzed in the same manner. Results for water and soil samples were reported in parts-per-million (for solids, μg/g; for liquids, μg/ml). The results for air samples were reported in units of $\mu g/m^3$.

4.4 Reduction of Data

The objective of the data analysis was three-fold:

1) to make modifications and deletions as needed to the original "raw" data set so as to arrive at one which is a valid representation of the data as taken in the field;

2) to determine which (if any) variables influence and affect the concentration values; and

3) to summarize the data in such a manner that the conclusions of the analysis are easily supported and communicable.

The first step (arrival at a valid data set) was a problem due to the nature and size of the original raw data set. The original data set was in fact a physical merging of several basic data sets--one having to do with air samples, another with water samples, and a third with soil samples. The original raw data acquisition for these 3 general areas was often performed manually by different people and on different recording forms with the net result that transcription errors were introduced both from the original recording and during the data merging.

The response variable of interest is of course, concentration. However, there were several other possibly influential variables to be recorded along with a given concentration:

1. container number
2. element (Hg, Pb, Cd)
3. site identification
4. collection month
5. collection day
6. type of sample (air, water, soil, etc.)
7. collector
8. analysis month
9. analysis day
10. x-coordinate for the site
11. y-coordinate for the site.

Inasmuch as there were originally 3874 concentration values measured and each concentration value was accompanied by values of the 11 other variables, this required the construction (for subsequent analysis) of a computer data file with (3874 x 12 =) 46488 values therein. With such a large original data file, a number of transcription and keypunch errors are certain to occur. The first step (and a continuing step throughout the analysis) was to "clean up" the data file to detect and remove errors due to transcriptions or other reasons. Weeding out such errors in a judicious fashion so as to avoid allowing such biases to affect the conclusions was clearly the first priority.

Corrections to the data file were applied at several stages of the entire analysis -- as one or another aspect of the data examination was carried out, and when the subsequent data anomalies were uncovered. The original data file, consisting of 3874 concentration readings plus associated variables, were iteratively corrected and reduced to a final "cleaned up" file of 3735 concentration readings and associated variables.

In toto, about a dozen computer programs were written and applied to the data file for the data correction, data analysis, and data summarization stages. The purpose of any given program often overlapped into 2 and sometimes all 3 areas (correction, analysis, summarization).

The following is a brief description of the various steps (programs) that were applied in the analysis. As will be noted, many of the techniques applied were graphical in nature -- such graphics have proven to be the most effective way of uncovering (and correcting) suspected (and unsuspected) anomalies in the data. All of the programs utilized made use of the ANSI FORTRAN data analysis solution library DATAPAC [29].

The initial step in the analysis consisted of generating 12 run sequence plots -- one plot for each of the 12 variables of interest (concentration, container number, element, site ID, etc., ...) A given run sequence plot consisted of 3874 points and plotted the variable of interest Xi (vertically) versus the dummy index i (i = 1, 2, ..., 3874) horizontally. The vertical axis limits were examined on each plot and often revealed keypunch or transcription errors which were reflected in data minima and maxima several orders of magnitude from what they should be. This of course led to the correction of those particular values in the data file which produced such discrepancies.

The second step in the analysis consisted of a simple rearrangement and grouping of the data file so as to facilitate (both from a time and computing expense point-of-view) all remaining steps. The original data file was ordered according to the day and month collected. A more efficient ordering however is one based on the 3 elements (Hg, Pb, Cd) and on the 11 sample types (silver wool, air filters, sewer, etc.) The resulting secondary file consisted of the same number of lines but was arranged into (3 x 11 =) 33 distinct blocks of data. This modularized data file greatly facilitated the examination of individual element sample type combinations.

Having isolated the 33 primary subsets of interest, the next step in the analysis consisted of applying various statistical techniques to each subset to exhaust information regarding the distribution of concentration values for each cell. Specifically, this was accomplished via frequency distribution enumeration, histograms, normal probability plots, and various summary statistics (subset means, modes, medians, minima, maxima, ranges, standard deviations, etc.) At this point in the analysis, an initial feel is obtained as to how the concentration values are varying for each element - sample type combination.

The next step in the analysis consisted of determining if the concentration values varied as a function of (collection) time. To achieve this end, plots of concentration versus collection time were examined for the following combination of factors:

all 3 elements

4 (out of the 11) sample types

12 (out of the approximately 120) sites

On the basis of the above, it was concluded that no significant drifting in concentration values existed as a function of time.

The above analysis was followed by a similar but more global look at the time dependence problem -- this consisted of plotting average (over all sites) concentration versus collection month. The usual 33 plots were analyzed for such time dependency -- one for each of the element - sample type combinations. The earlier conclusion of no significant time dependence was corroborated.

Yet another step in this same direction was taken by examining average concentration versus collective month plots for the following 9 combinations of 2 factors:

3 elements

3 general sample types (air, water, soil)

A given average concentration value that appeared on a plot consisted of the average of all concentration readings over all sites for that particular element, general sample type, and collection month. Again, no time dependence was detected.

The next steps in the analysis shifts attention from the time factor to the site factor. Analyses were carried out for each of the following combination of factors:

3 elements

11 sample types

120 sites

For a given element and sample type, the concentration values for each site were isolated, enumerated, and the appropriate summary statistics (mean, median, minimum, maximum, range, standard deviation, etc.) computed.

All of the above summary statistics were computed over (i.e., without regard to) the collection months inasmuch as this latter variable was seen to have a negligible effect. Summary tables were generated and examined which contained all of the above concentration statistics as a function of each site, element, and sample type. Plots were formed which plotted above-average concentration versus site for each element sample type combination.

The next step in the analysis was to determine (for a given element and sample type) if a given site had an unusual reading relative to all of the other sites. To determine such, the concentration averages of all the sites were grouped from which a grand average $\bar{\bar{x}}$ and the group standard deviation was computed and tabulated. The individual site averages were then compared to this grand average and it was determined how many standard deviations away from the grand average were the individual site averages, $\bar{x}_i$. Sites with extreme deviations from $\bar{\bar{x}}$ were flagged and noted. The number of site averages in the following categories were computed:

$$\bar{x}_i \leq \bar{\bar{x}}$$

$$\bar{\bar{x}} \leq x_i \leq \bar{\bar{x}} + \sigma$$

$$\bar{\bar{x}} + \sigma \leq \bar{x}_i \leq \bar{\bar{x}} + 2\sigma$$

$$\bar{\bar{x}} + 2\sigma \leq \bar{x}_i \leq \bar{\bar{x}} + 3\sigma$$

$$\bar{x} \leq 3\sigma \leq \bar{x}_i$$

A special statistical procedure was then applied to automatically flag extreme site averages. These were examined for credibility, using the criterion that real values would be supported by other data obtained at the same location.

The final step was to geographically summarize the above comparison of individual site averages to the grand average. The 33 (3 elements x 11 sample types) plots were generated on the Tektronix 4014 display terminal by use of software developed for such graphics. An outline of Washington was first produced and a coded (in terms of σ) value representing the relative value of each site was superimposed. The coding values utilized were as follows:

Value	Code
$\bar{x}_i \leq \bar{\bar{x}}$	0
$\bar{\bar{x}} \leq \bar{x}_i \leq \bar{\bar{x}} + \sigma$	1
$\bar{\bar{x}} + \sigma \leq x_i \leq \bar{\bar{x}} + 2\sigma$	2
$\bar{\bar{x}} + 2\sigma \leq \bar{x}_i \leq \bar{\bar{x}} + 3\sigma$	3
$\bar{\bar{x}} + 3\sigma \leq \bar{x}_i$	4

Hot spots in the city are identified on corresponding maps by relatively large (e.g., 3 or 4) coded values. The coded (in terms of σ) representation of the results allows one to graphically summarize the results in a clear and concise fashion.

5. SUMMARY OF DATA

A total of 3787 data points were obtained as a result of the measurements described above. Of these, 49 were considered to be invalid, based on credibility considerations outlined in Section 4.4. Accordingly, 98.7 percent of the data was judged to be valid and used in the following discussion.

Tables 1, 2 and 3 contain a summary of the data, classified according to measurements of mercury, lead, and cadmium, respectively. The data are classified into the following arbitrary groups:

Group	Concentration Range
0	$x < \bar{x}$
1	$\bar{x} < x \leq \bar{x} + s$
2	$\bar{x} + s < x \leq \bar{x} + 2s$
3	$\bar{x} + 2s < x \leq \bar{x} + 3s$
4	$\bar{x} + 3s < x$

The tables list: sample type, the number of sites sampled for each type; the total number of samples for each type; the range of values obtained; the mean concentration, $\bar{x}$; the standard deviation, s; the number, n, and percentage of sites with average values in each group, and the upper limit of concentration for each group.

Histograms were generated by the computer to show the distribution of measurement for each sample type. Representative diagrams for lead in air, mercury in water, and lead in street dust are given in Figures 3,4, and 5, respectively. The distribution in each case is not "normal" because of cut-offs on the low side of each histogram, due

to sensitivity limitations of the analytical methods. Analytical values below the instrument detection level were not interpreted as zero, but as the detection limit value.

Figures 6 to 14 show summary plots of monthly average concentrations with respect to time for the three elements for air, water, and soil samples as indicated. Not all of the sample types were measured throughout the entire period, therefore these plots are useful only for indication of general aspects of the data.

Maps 1 to 25 show yearly average concentrations found at the indicated locations, for the three elements and eight sample types. The symbols 0,1,2,3, and 4 indicate concentration groups defined above and quantitatively given in Tables 1,2, and 3.

6. DISCUSSION OF DATA

Some interesting inferences may be drawn from consideration of the data of Tables 1,2, and 3, and these will be discussed in that order.

The following observations can be made from consideration of the data for mercury of Table 1.

(a) As can be seen when comparing $\bar{x}$ for mercury in the elemental form (silver wool) and the particulate form (air filters), most of the mercury in the air is elemental mercury, rather than particulate mercury.

(b) Even though the mean value of the mercury content of sewer water is below the permissible drinking water standard indicating no significant emissions of mercury into the waste water system, the sewer water has a much higher range indicating that mercury input is quickly diluted to an acceptable level.

(c) The hot and stagnant water samples are not enriched, indicating no leaching of mercury from the distribution system.

(d) The mercury concentration appears to increase in the order street dust < topsoil < subsoil, suggesting a general movement downward of mercury into the soil or possibly surface depletion by volatilization.

The following general observations can be made concerning the data for lead in Table 2.

(a) The lead enrichment from drinking water to sewer water was not significant indicating no major input of lead into the sewer system.

(b) The stagnant water lead concentration was greater than the hot water lead concentration which was greater than drinking water concentrations in locations especially selected to test leaching characteristics. This is consistent with the known ability of water to extract metals from plumbing systems. However, the highest lead levels found were still significantly below those permitted by the drinking water standards, indicating no imminent hazard.

(c) Lead concentrations in street dust exceeded that of topsoil which in turn exceeded that found in subsoil. This supports the findings of others that lead pollution is largely from the air and probably arises from automotive sources [7-10, 26-27].

The data of Table 3 for cadmium suggest the following:

(a) The near identity of concentrations of cadmium in drinking water and sewer water indicate no major input of cadmium into the latter.

(b) No leaching of cadmium from plumbing systems was observed.

(c) A slight enrichment of cadmium in comparison of street dust with topsoil is similar to that observed by others and explained as resulting from abrasion of cadmium-containing rubber from automobile tires [26].

A general conclusion from the three tables is that bottom sediments contain significant concentrations of all three elements. Further work would be required to determine their source, i.e., whether the sediment is acting as a sink or whether the metals result from transport from other areas.

Computer-generated profiles, such as those shown in Maps 1 to 25, provide a convenient means to intercompare environmental data on a geographical basis. They present an overall view of the pollution levels in the area of display and identify the locations of any abnormalities.

In the present case, the overall conclusion is that levels for any of the three elements are not at an alarming stage either area-wide or in any specific location for any type of sample. However, spots have been identified which are clearly above average level and these should be the ones subjected to continued study.

Tables 4, 5, and 6 contain a comparison of some of the analytical values found in this work with those reported by others. The only marked difference noted is the value for lead in air particulates of 0.19 $\mu g/m^3$ which is lower than that usually reported in urban atmospheres. More work would be required to determine whether this is a real difference and whether there has been a significant improvement in the lead concentration as compared to the earlier values reported for the Washington, D.C. area [8].

7. RECOMMENDATIONS

7.1 Sampling

The development of a suitable sampling plan is a major problem in an environmental survey and merits all the effort that can be devoted to it. Experience has shown that redundancy is the best insurance to maximize confidence in the results. Enough replicates of sub-samples need to be made to identify analytical variance while replicate samples need to be measured to assure credibility to any reported data.

Credibility is increased by using the technique described by J.W. Bewers et al (28) in a paper entitled "Data Are for Looking At or Quality Control Through Interpretation". In it, they recommend inspection at all stages for credibility based on the sampler's idea of what a representative sample looks like, on the analyst's feeling for the measurement process and knowledge of what result is expected, and on the environmentalist's ability to detect anomalies. Corrective feedback action can be taken at any one of the stages to determine whether the particular item - sample, measurement, data - is credible. Obviously, incredibility needs to be detected in its earliest possible stage.

Such a chain of examination was followed in the present case. The samplers were thoroughly trained by NBS to minimize taking useless samples. The analytical work was done by a competent analyst who was given special assistance by NBS experts in the use of the specific analytical techniques.

Data inspection was used as mentioned in Section 4.4 to eliminate "outliers". The philosophy was followed that data must be repeatable to be meaningful. Values showing large deviations from the mean, e.g., greater than 3 standard deviations, were individually examined and retained only if other data were found to support them. As the result of

this practice only 49 values were excluded out of 3,787 data points, and these appeared to be clearly outliers. For example, a drinking water sample was found to have a mercury content many times that of waste water. Even if the data were real, the explanation of this solitary event - contamination, foreign object, etc. - could hardly be environmentally significant. All excluded data has been retained for further reference should it recur, and this was the policy adopted here. However, the data should not be included in averages, or otherwise interpreted unless validated by additional work.

7.2 Homogenization of Samples

Soil samples, in the broad sense of the term, provide major problems, ranging from when to take the sample, what constitutes a representative sample, and what pre-treatment should be undertaken before analysis.

The designated spot may contain little or no material generally recognized as the sample type. In such a case, the sample site must be moved to a more significant spot, or eliminated entirely. The major decision will be concerned with what is the sample at a spot recognized to be appropriate for sampling. Some arbitrary decision may need to be made. The sampler should avoid including any "foreign" objects or material with what is otherwise known to be the sample. For example, rocks, discarded trash, animal or vegetable matter should be excluded, since these may disintegrate during transport or storage and be unknowingly incorporated into the analytical sample. A general rule is to exclude all matter which is obviously foreign but to note such an exclusion on the sample label.

Because of the variabilities in moisture content, sample pre-treatment ordinarily includes a drying step. On the other hand, vigorous drying can cause loss of constituents sought. If volatile or labile materials, such as pesticides and organic constituents, are of interest, the analysis may need to be made on "as is" samples with moisture content determined on a separate sample.

Whenever possible pre-drying of the sample is preferred to facilitate the mixing process. Gross sieving is a recognized method of eliminating foreign material and this, preceded by breaking up of clumps, will facilitate mixing of the sample.

For the most representative sample from a given lot, it is preferable to remove a number of small portions from the sieved lot, and to mix these to form a composite before taking a subsample. The largest sample possible, consis-

tent with the analytical method should be taken. It is better to take replicate subsamples from replicate composites.

However, more information is gained from replicate samples than from replicate subsamples. In dealing with heterogeneous material such as soils, it is wise to increase the number of samples and to analyze by a method of adequate reliability than to use the most sophisticated (and correspondingly more expensive) technique on a small number of samples.

In the work reported here, the sample treatment plan consisted of drying the samples for 8 hours or more at 60 °C followed by sieving with a #30 mesh screen. All weights were recorded including loss on drying and loss on sieving. This procedure eliminated some glaring inconsistencies in the early data.

The analysis of soil samples is complicated by the question of bioavailability of the substance measured. Obviously all of the material may not be biologically significant. Procedures used by others have ranged from "total" element resulting from quantitative solution of the sample to an equilibration with the receiving water. In the present case, the EPA procedure for digestion with nitric acid was used and probably represents the upper limit of bioavailability. No problems were encountered in using this procedure.

7.3 Record Keeping

Record keeping is a major problem in an extensive survey such as the one undertaken here. Accordingly, a carefully considered "Chain-of-Custody" needs to be developed and followed. A detail which would be followed if further work were done, would be to assign a permanent number to a sample container, but a different unique number to each sample. Computer programs could then be used to identify any cross-contamination that might be suspected.

Data should also be recorded in a format that would simplify its use in data reduction, e.g., its transferral to punch cards. The data analyst should be helpful in devising a suitable format. This was not done in the present work and additional labor was expended as a result. Such a format would also minimize the chance of error in data transcription.

8. CONCLUSIONS

The distribution of toxic substances in the environment may be due to their origination from localized sources or

from multiple sources widely (often randomly) located within the area. The latter results in ubiquitous distributions, the concentration level of which must be ascertained by widespread sampling over an extended period of time.

The concentration levels found may be high enough for considerable concern and attention, they may be within generally considered safe levels, or they may indicate continued surveillance to determine whether adverse trends are in progress. The present results appear to indicate the middle situation. However, continued surveillance of the few spots where elevated levels were found would be prudent.

The techniques developed during the course of this work should greatly facilitate continued surveillance of this area as well as similar studies undertaken in other areas and/or with other ubiquitous toxic substances. The computer techniques should greatly facilitate data reduction and analysis and provide a convenient means to obtain both an overall level of a given toxic substance as well as to locate areas for further study or continued surveillance.

The recommendations given in Section 7 should be useful for continuation of the present survey or to those planning similar surveys.

9. ACKNOWLEDGEMENTS

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APPENDIX I

IA. Air Sampling Stations

A1. Fourth District Police Headquarters
Georgia Avenue & Peabody Street, N.W.

A2. Catholic University, Biology Building
7th & Michigan Avenue, N.E.

A3. St. Elizabeth's Hospital, Guard House No.3
Martin Luther King Avenue, S.E.

A4. DC General Hospital, Doctor's Residence Hall
19th & Massachusetts Avenue, S.E.

A5. National Arboretum
24th & R Streets, N.E.

A6. 801 N. Capitol St., N.E.

A7. Tenley-Friendship Library
Wisconsin Avenue & Albemarle Street, N.W.

A8. West End Library
24th & L Streets, N.W.

A9. CAMP Station
427 New Jersey Avenue, N.W.

A10. Cleveland Park Library
Connecticut Avenue & McComb Street

The locations of these air sampling stations are shown on Map-1.

APPENDIX I

IB. Sewer Sites

The sewer collection sites are given below and are shown on Map 2.

No.	Location	Coverage
-210	Nash & Fairlawn Streets	SE Residential
-200	First & "O" Streets	SW Residential
-190	Connecticut & Upton Sts.	Old NBS Area
-180	Military Road	Rock Creek Park
-170	Luzon & Aspen Streets	Walter Reed Hosp.
-160	Near National Aboretum	NY Ave. Industrial Area
-150	9th & Maine Ave.	Maine Ave. Boat Marina
-140	Near GW Univ.	Various Hospital Labs
-130	22nd St & "P" St.	Dupont Circle
-120	Canal Road near GU	GU Medical Ctr.
-110	42nd & Edmund St.	NW Residential
-100	Reno Road	NW Industrial
-90	Mass Ave. & Tilden St.	American Univ.
-80	5th & Ingraham St.	Riggs Rd. Industrial Area
-70	Brookland Ave. near C.U.	Catholic Univ.
-60	Georgia Ave at H.U.	Howard Univ.
-50	Michigan Ave & Park Place	Wash. Hosp. Ctr.
-40	North Capitol & "E" St.	Union Station
-30	Anacostia Ave. S. of Benning Rd.	Incinerator-PEPCO Area
-20	Front entrance of DC Jail	DC General Hosp.
-10	Suitland Parkway	St. Elizabeth's Hosp.

APPENDIX I

IC. Soil and Water Sampling Sites

The sampling sites are listed below and shown on Map 3.

1. BLUE PLAINS

1 Soil samples were taken in front of the "Heat Exchange" building; drinking water was taken from the drinking fountain inside the lab. Hot and stagnant water samples were taken from the hot water tap inside the lab.

3 Soil samples were taken between the trees and the railroad tracks at the point where the tracks cross the entrance road.

4 Soil samples were taken near the front gate.

#102 Bottom sediment samples were taken from the Potomac near the new Administration Building. River water samples were taken from the same location.

#112 "Makeup water for elutriation" was taken from the first open vat next to the lab.

83 "Primary water" was taken in the basement of the heat exchange building. The left hand lever is for primary water.

84 "Secondary water" was also taken in the basement of the heat exchange building. The right hand lever is for secondary water.

#109 The "Primary in" water was taken from one of the center tanks in the new aerated brick chamber.

#110 The "Primary → Secondary" water was taken from any of the four tanks near "E" or "F" house.

2. CONGRESS HTS.

6 Soil and street dust samples were taken at the corner of Alabama and Randle Place.

3. ST. ELIZABETH"S HOSPITAL

#700 Soil samples were taken in front of the WW Eldrige Building, while water samples were taken from the water taps inside the visitor's restroom.

#710 Soil samples were taken near the old incinerator site.

4. ANACOSTIA

9 Soil samples were taken in back of the McDonald's restaurant on the corner of Good Hope Road and 16th Street. Water samples were taken inside.

5. FT. STANTON PARK

8 The soil samples were taken between the street and the baseball field. The water samples were taken from the drinking fountain.

6. FT. DUPONT PARK

10 The soil samples were taken between the street and the tennis courts. The water samples were taken from a nearby drinking fountain.

7. DEANWOOD

12 The soil samples were taken on the corner of 49th Street NE and Sheriff Road. The water samples were taken from the nearby Exxon gas station.

8. BENNING HTS.

11 The soil samples were taken on the corner of 44th and Blaine Streets, SE. The water samples were taken from the nearby Sunoco gas station.

9. PEPCO

31 The soil samples were taken from the corner of Benning Road and 34th Street, NE. The water samples were taken from Phil's Gulf gas station.

32 The soil samples were taken between the side walk and street across from the Pep Boy's Store on Minnesota Avenue near Benning Road.

33 The soil samples were taken on the corner of Foote Street and Kenilworth Terrace.

#118 The oil sample was obtained from the PEPCO plant manager.

26 The "discharge water" sample was taken from a manhole just inside the fence near the front gate.

#260 The drinking water sample was taken from inside the PEPCO office building.

27 The "decant water" sample was taken from the ash settlement tank inside the PEPCO fence.

10. INCINERATOR

18 The soil samples were taken in front of the office parking lot. The drinking water samples were taken inside the administration building and the sewer samples were taken from the manhole where the ash wash water is discharged into the sewer.

19 The soil samples were taken near the weigh station.

20 The soil samples were taken in the southeast corner next to the PEPCO fence.

21 The soil samples were taken near the front entrance at the PEPCO parking lot.

22 The soil samples were taken near the basket-ball - tennis courts and the water samples were taken from the drinking fountain.

11. RIVER TERRACE

16 The soil samples were taken on Anacostia Avenue near the River Terrace tennis courts. The drinking water samples were taken from a nearby drinking fountain.

96 The bottom sediments were taken from the Anacostia River near the park. The river water sample was taken next to the park upstream from the PEPCO discharge.

29 The river water sample was taken on the bank near the point of discharge from PEPCO into the Anacostia River.

12. THOMAS ELEMENTARY SCHOOL

23 The soil samples were taken in the play area near the back of the school. The water samples were taken from a nearby water faucet.

13. ABORETUM

37 The soil samples were taken under the large tree across from the parking lot. The water sample was taken from the drinking fountain nearby.

14. LINCOLN PARK

34 The soil samples were taken between the street and sidewalk on E. Capitol Street, near the center of the park. The water samples were taken from the fountain located within the park.

15. RFK STADIUM

17 The soil samples were taken from the grass island directly in front of RFK Stadium.

16. DC GENERAL

15 The soil samples were taken near the reserved parking lot. The water samples were taken inside the visitor's center.

17. ANACOSTIA RIVER

97 The soil samples were taken near the river at the end of "M" Street. The bottom sediment and water samples were taken from the river at the same location.

98 The soil samples were taken near the wharf at the end of "N" Place. The bottom sediment and water samples were taken from the river at the same location.

18. BP PEPCO

#1180 The oil sample was obtained from the PEPCO plant manager.

#1221 The fly ash sample was obtained from the PEPCO plant manager.

#1220 The drinking water sample was taken from the drinking fountain located inside the PEPCO administration building.

122 The soil samples were taken on the corner of First and "V" Streets, SW.

123 The soil samples were taken on the corner of Half and "S" Streets, SW.

124 The soil samples were taken on the corner of "T" and Second Streets, SW.

125 The soil samples were taken on the corner of Second and "V" Streets, SW.

120 The water samples were taken from the Potomac River bank near the point of intake into the PEPCO plant. Bottom sediment samples were taken from the same area.

121 The water samples were taken from the Potomac River bank near the point of discharge into the Potomac. Bottom sediment samples were taken from the same area.

19. BOAT MARINA

#128 The soil samples were taken underneath the overpass near the boat marina on Maine Avenue. Drinking water was taken from a faucet nearby. River water was taken in the same location.

#135 River water was taken at the point of discharge into the river by the power plant.

20. HAWTHORNE H.S.

35 The soil samples were taken on the corner of 6th and "I" Streets, SW. The water samples were taken from the nearby fountain.

21. U.S. CAPITOL

36 The soil samples were taken underneath one of the large trees at the rear of the Capitol Building. The water samples were taken from a nearby faucet.

22. UNION STATION

38 The soil and street dust samples were taken in front of Union Station. The water samples were taken from the restroom inside.

#39 The soil samples were taken on the corner of "I" Street and First Street, NE. The water samples were taken at the nearby Sunoco gas station.

40 The soil samples were taken on the corner of Patterson and First Streets, NE.

41 The soil samples were taken on the corner of "K" and Second Streets, NE between the sidewalk and the wall.

42 The soil samples were taken on the corner of "G" and Second Streets, NE.

23. TRAIN YARD

45 The soil samples were taken in the parking lot on the corner of 4th and Penn Streets, NE.

47 The soil samples were taken from the empty lot across from the Police Station on the corner of Bladensburg and "T" Streets. The water samples were taken from the Police Station.

46 The soil samples were taken near the railroad tracks on the corner of 14th and "W" Streets, NE.

44 The soil samples were taken on the corner of "W" and 5th Streets, NE.

43 The soil samples were taken on the train yard side of the street on the corner of "Q" Street and Eckington Place.

24. BRENTWOOD PARK RESERVOIR

95 Bottom sediment and water samples were taken from Brentwood Park Reservoir.

25. NE GARAGE

#136 Street dust samples were taken from the pile of dumpings at the Northeast Garage where Washington, D.C. street sweepings are dumped.

26. ECKINGTON

51 Soil samples were taken on the corner of First and "S" Streets, NW.

27. HOWARD UNIVERSITY

#129 Soil samples were taken across from the Physical Plant Building on 6th Street near the corner of 6th and "W" Streets, NW. The water samples were taken from a nearby water faucet.

28. McMILLIAN RESERVOIR

94 Water samples were taken from McMillian Reservoir.

29. WASHINGTON HOSPITAL CENTER

#130 Soil samples were taken near the main entrance parking lots. Water samples were taken inside.

30. CATHOLIC UNIVERSITY

50 The soil samples were taken in the wooded area near the tennis courts parking lot. The water samples were taken from a nearby faucet.

31. BROOKLAND

#48 The soil samples were taken on the corner of 18th and Monroe Streets, NE. The water samples were taken from the Shell station nearby.

32. TERRA COTTA

#49 The soil samples were taken on the corner of South Dakota and 13th Place, NE.

33. MANOR PARK

#60 The soil samples were taken on the corner of Blair Road and Sheridan Street.

34. WALTER REED

#61 Soil samples were taken on the corner of Butternut and Georgia Avenue on the hospital side of the street.

35. NORTH GATE

#62 Soil samples were taken near the Metrobus sign in front of the Washington Ethical Society Building (7750 16th Street, NW).

36. BRIGHTWOOD PARK

#59 Soil samples were taken between the sidewalk and street on the corner of 8th and Longfellow, NW.

37. GRANT CIRCLE

#58 Soil samples were taken at Grant Circle near 5th Street, NW. Water samples were taken from a fountain inside Grant Circle.

38. CRESTWOOD-1

#56 Soil and street dust samples were taken on the corner of 16th and Upshur Streets, NW.

39. CRESTWOOD-2

#57 Soil samples were taken at the end of Upshur at Rock Creek Park.

40. COLUMBIA HEIGHTS

#55 Soil samples were taken on the corner of 13th and Euclid Streets, NW.

41. LOGAN CIRCLE

53 Soil and water samples were taken inside Logan Circle.

42. DUPONT CIRCLE

54 Soil and water samples were taken inside Dupont Circle. Street dust samples were swept from the street.

43. ELLIPSE

52 Soil samples were taken between Constitution Avenue and the Ellipse. Water samples were taken from a nearby fountain.

44. TIDAL BASIN

99 Soil, bottom sediment and water samples were taken at the tidal basin near the Jefferson Memorial.

45. POTOMAC-3

#104 Soil, bottom sediment and river samples were taken near the tidal basin outlet to the Potomac on the West Potomac Park side of Ohio Drive.

46. HAINS POINT

13 Soil, bottom sediment, river water and drinking water samples were taken at Hains Point.

47. WASHINGTON CHANNEL

#100 Soil, bottom sediment, street dust and water samples were taken from or near the Washington channel at the parking lot across from the Ft. McNair Smoke Stacks.

48. T. ROOSEVELT ISLAND

82 Soil, bottom sediment and river water samples were taken near the end of the walkway onto T. Roosevelt Island. Drinking water samples were taken from the fountain at the monument.

49. COLUMBIA ISLAND

#134 Soil, bottom sediment and river water samples were taken on Columbia Island near George Mason Memorial Bridge.

50. GEORGETOWN

81 Soil samples were taken on the corner of 31st and "N" Streets, NW.

51. ROCK CREEK - 4

#133 Soil, bottom sediment and river water samples were taken underneath the bridge at 26th and "M" Streets, NW.

52. POTOMAC - 6

#107 Soil and river water samples were taken at the Potomac River at the end of Wisconsin Avenue.

53. GEORGETOWN UNIVERSITY

80 Soil and street dust samples were taken at Georgetown University across from the Medical Center on Reservoir Road. Water samples were taken from a nearby faucet.

54. U.S. NAVAL OBSERVATORY

79 Soil samples were taken on the corner of Observatory Circle and Massachusetts Avenue across from the British Embassy.

55. CLEVELAND PARK - 1

72 Soil samples were taken on the corner of 36th and Ordway Streets.

56. CLEVELAND PARK - 2

73 Soil samples were taken on the corner of Connecticut Avenue and Rodman Street.

57. FT. RENO PARK

68 Soil samples were taken in Ft. Reno Park on the corner of Chesapeake and 40th Streets. Water samples were obtained from a nearby drinking fountain.

58. BARNABY WOODS

65 Soil samples were taken on the corner of Utah and 32nd Streets.

59. ROCK CREEK - 1

63 Soil, bottom sediment and river water samples were taken from Rock Creek at parking area #10. Drinking water samples were taken from a nearby drinking fountain.

60. ROCK CREEK - 3

#131 Soil, bottom sediment and river water samples were taken near the bridge on Beach Drive at the Montgomery County line.

61. ROCK CREEK - 2

64 Soil and street dust samples were taken at the parking lot near Military Road bridge. Bottom sediment and river water samples were taken from Rock Creek at this location. Drinking water samples were taken from a fountain near the log cabin.

62. LITTLE FORREST PARK

66 Soil samples were taken on the corner of 30th Street and Military Road.

63. TENLEYTOWN

69 Soil samples were taken on the corner of 38th and Warren Streets.

64. LISNER HOME

67 Soil samples were taken in the park on Fessenden Street between 46th and 47th Streets, NW. Water samples were taken from a nearby fountain.

65. AMERICAN UNIVERSITY

71 Soil samples were taken in front of the Chemistry Building. Water samples were taken from a nearby faucet.

66. WESLEY HEIGHTS

74 Soil samples were taken on the corner of Dexter Street and 49th.

67. MT. VERNON J.C.

77 Soil samples were taken near the Science Building. Water samples were taken inside the Science Building.

68. GEORGETOWN RESERVOIR

78 Water samples were taken from the Georgetown Reservoir.

69. PALISADES

76 Soil samples were taken on the park side of Arizona Street near Klingle.

70. POTIMAC HEIGHTS

75 Soil samples were taken on the corner of Potomac Avenue and Newark Street.

71. DALECARLIA

70 Soil samples were taken near the main gate at Dalecarlia.

#7000 "Raw Water" samples were taken inside the Dalecarlia Chemistry Laboratory.

#7001 "Treated Water" samples were taken inside the Dalecarlia Chemistry Laboratory.

72. CANAL - 2

#132 Soil and street dust samples were taken on Canal Road 0.8 miles south of Chain Bridge. Bottom sediment and water samples were taken from the canal at the same location.

73. CANAL - 1

#1030 Soil, bottom sediment and water samples were taken from the canal on the Washington, DC side of Chain Bridge.

74. POTOMAC - 2

#103 Soil, bottom sediment and river water samples were taken from the Potomac River on the Virginia side of Chain Bridge.

Table I. Summary of Mercury Data

Sample Type	Number of Sites	Number of Samples	Range	Mean, $\bar{x}$	Standard Deviation s	Group 0		Group 1			Group 2			Group 3 and 4	
						n	%	Upper Limit	n	%	Upper Limit	n	%	n	%
Silver Wool	10	54	.0135- .0303	.0212	.0208	6	60	.0420	4	40	.0628	0	-	0	-
Air Filters	10	41	.0003- .0081	.0015	.0029	8	80	.0044	1	10	.0073	0	-	1	10
Sewer	21	144	.0001- .0050	.0017	.0028	13	62	.0045	7	33	.0073	1	5	0	-
River Water	11	20	.0000- .0003	.0001	.0001	7	64	.0002	3	27	.0003	0	-	1	9
Drinking	26	38	.0000- .0013	.0002	.0003	18	69	.0005	5	19	.0008	2	8	1	4
Stagnant	14	22	.0000- .0004	.0001	.0002	10	71	.0003	2	14	.0005	2	14	0	-
Hot Water	14	22	.0000- .0006	.0002	.0003	9	64	.0005	4	29	.0007	1	7	0	-
Topsoil	99	482	.0875-2.0849	.3800	.3693	56	57	.7493	36	36	1.1187	3	3	4	4
Subsoil	99	389	.0300-2.2467	.5944	.7160	61	62	1.3104	29	29	2.0264	8	8	1	1
Street Dust	15	39	.0300- .8550	.3297	.2819	9	60	.6117	5	33	.8936	1	7	0	-
Bottom Sediments	7	25	.0600-1.0600	.3016	.3677	5	71	.6693	1	14	1.0370	0	-	1	14

*Silver Wool and Air Filter concentrations are $\mu g/M^3$; all other concentrations are ppm.

Table 2. Summary of Lead Data

Sample Type	Number of Sites	Number of Samples	Range	Mean, $\bar{x}$	Standard Deviation s	Group 0		Group 1			Group 2			Group 3 and 4	
						n	%	Upper Limit	n	%	Upper Limit	n	%	n	%
Air Filters	10	41	.0995-.3050	.1910	.1529	6	60	.3440	4	40	.4969	0	-	0	-
Sewer	21	144	.0116-.1238	.0525	.0758	12	57	.1308	9	43	.2091	0	-	0	-
River Water	11	22	.0020-.0360	.0123	.0113	7	64	.0236	2	18	.0348	1	9	1	9
Drinking	25	34	.0001-.0110	.0035	.0030	16	64	.0065	5	20	.0095	3	12	1	4
Stagnant	13	21	.0007-.0570	.0119	.0203	9	69	.0402	2	15	.0605	2	15	0	-
Hot Water	14	21	.0010-.0170	.0068	.0083	9	64	.0151	2	14	.0234	3	21	0	-
Topsoil	99	484	22-1227	301	395	67	68	696	24	24	1090	7	7	1	1
Subsoil	99	390	20-1029	160	230	70	71	390	20	20	619	7	7	2	2
Street Dust	16	40	18-2514	715	235	9	56	1350	4	25	1985	1	6	2	13
Botton Sediments	7	25	36-143	76	50	4	57	126	2	29	176	1	14	0	-

*Air Filter concentrations are in $\mu g/M^3$; all other concentrations are ppm.

Table 3. Summary of Cadmium Data

Sample Type	Number of Sites	Number of Samples	Range	Mean, $\bar{x}$	Standard Deviation s	Group 0		Group 1			Group 2			Group 3 and 4	
						n	%	Upper Limit	n	%	Upper Limit	n	%	n	%
Air Filters	10	40	.0015- .0038	.0026	.0015	5	50	.0040	5	50	.0055	0	-	0	-
Sewer	21	141	.0002- .0049	.0013	.0019	14	67	.0032	6	29	.0051	1	5	0	-
River Water	11	22	.0000- .0016	.0008	.0008	6	55	.0016	3	27	.0023	1	9	1	9
Drinking	25	37	.0000- .0010	.0004	.0004	15	60	.0008	7	28	.0012	3	12	0	-
Stagnant	14	23	.0000- .0026	.0003	.0006	10	71	.0009	3	21	.0015	0	-	1	7
Hot Water	14	22	.0000- .0018	.0005	.0006	8	57	.0011	5	36	.0018	0	-	1	7
Topsoil	99	475	.7492-5.4000	1.6406	1.1596	55	56	2.8002	36	36	3.9598	7	7	1	1
Subsoil	98	376	.1167-4.8000	1.5312	1.1448	62	63	2.6760	28	29	3.8207	7	7	1	1
Street Dust	16	40	.8000-4.4000	2.0342	1.3061	7	44	3.3403	7	44	4.6464	2	13	0	1
Bottom Sediments	7	25	.3000-1.2500	1.0240	1.3654	4	57	2.3894	3	43	3.7548	0	-	0	-

*Air Filter concentrations are in $\mu g/M^3$; all other concentrations are ppm.

Table 4. Comparison of Present Data with Values Found by Others — Air.

Location	Reference	Hg	Pb	Cd
		Elemental Hg		
Washington, DC	This Work	.021		
Chicago, IL	18	.022		
World Average	19	.020		
San Francisco	20	.001- .050		
World Wide	21	.003-2.00		
		Particulates		
Washington, DC	This Work	.0015	.19	.0026
Chicago	18	.0040		
World Wide	21	.0005-.0150		
Nation Wide	7		.9000	.0004
Nation Wide	9		1-3	
U.S.A. Urban	8		1.1	
U.S.A. Nonurban	8		0.10	
Washington, DC	8		1.08-2.34	

All values, $\mu g/M^3$

Table 5. Comparison of Present Data with Values Found by Others – Water.

Location	Reference	Hg	Pb	Cd
		Drinking Water		
Washington, DC	This Work	.0002	.0035	.0004
Permissable Level-75	5	.002	.050	.010
Windsor, Ontario	22	.0001		
		River Water		
Washington, DC	This Work	.0003	.0123	.0008
Windsor, Ontario	22	.0003		
Michigan	12	.0001-.0002		
Nationwide	15	.00002-.0007		
Israel	23		.0064	.0009
Nationwide	24	0-.005	.001-.050	.001-.010
		Sewer		
Washington, DC	This Work	.0017	.0525	.0013
New York City	25			.001-.007

All values, ppm (mg/L)

Table 6. Comparison of Present Data with Values Found by Others – Soil.

Location	Reference	Hg	Pb	Cd
		Topsoil		
Washington, DC	This Work	.3800	301	1.6406
Michigan	12	.0102		1.46
Nationwide	15	.020-.920		
Netherlands	8		555	
Champaign, IL	26		20-1060	1.0
		Street Dust		
Washington, DC	This Work	.3297	715	2.0342
Champaign, IL	26		240-6640	6-8
London	27		1200	
		Subsoil		
Washington, DC	This Work	.5944	160	1.5312
		Bottom Sediments		
Washington, DC	This Work	.3016	76	1.0240
Israel	23		8.4	0.7
Michigan	12	.1100	11	

All values, ppm (µg/g)

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Figure 7.	Monthly average concentrations of mercury in water plotted with respect to time (numerical value is month).
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Map 25 Area-wide distribution of average concentration of cadmium in topsoil.

Map 26 Area-wide distribution of average concentration of cadmium in subsoil.

Map 27 Area-wide distribution of average concentration of cadmium in street dust.

Map 28 Area-wide distribution of average concentration of cadmium in bottom sediments.

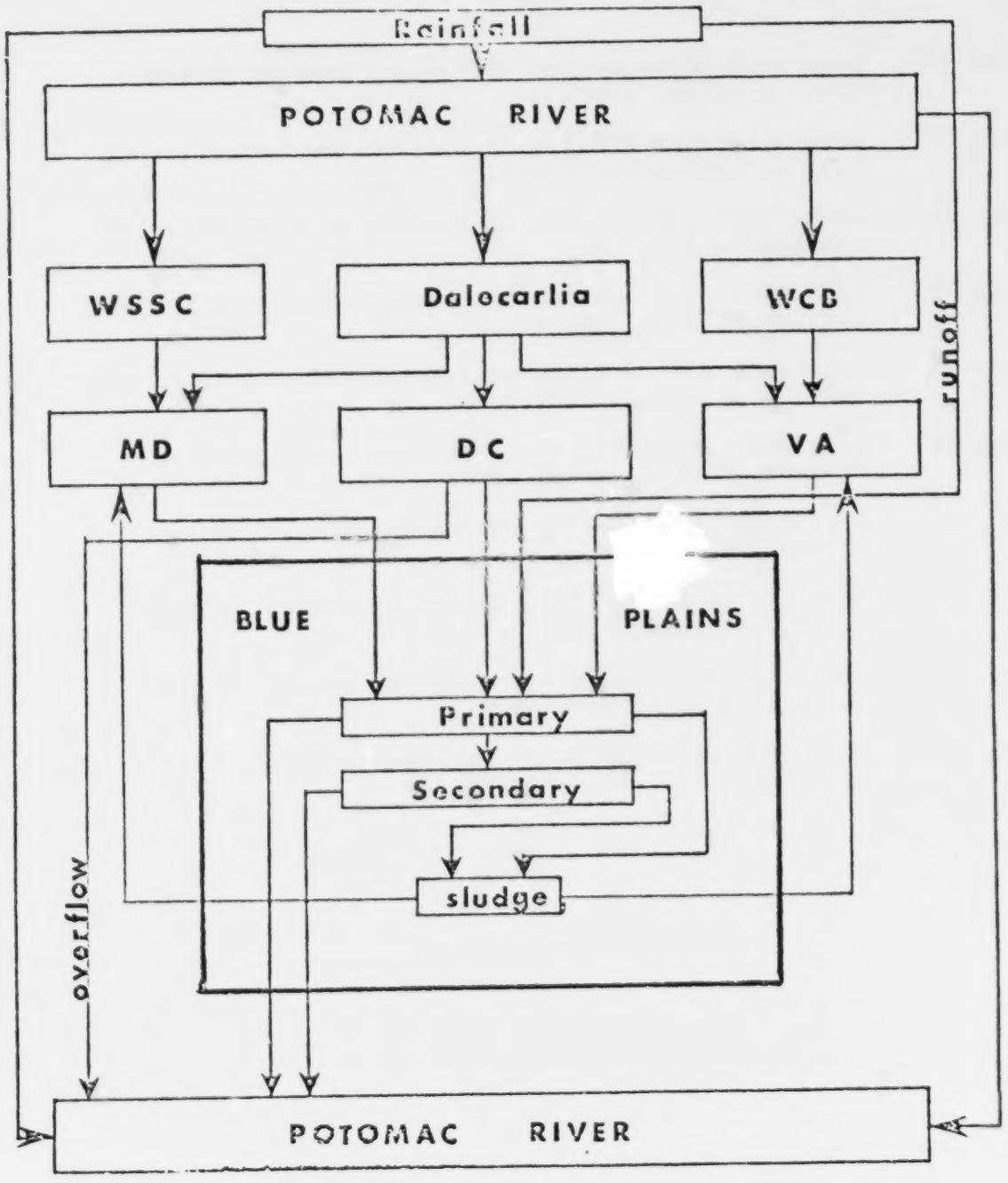
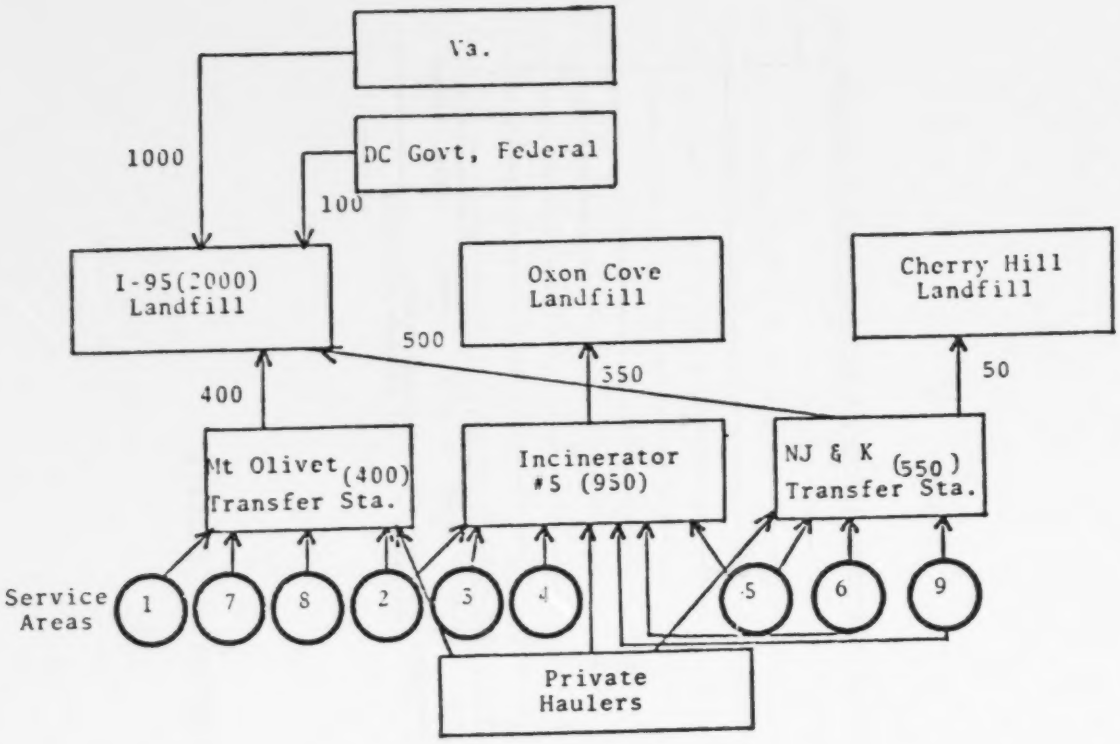


Figure 1. Schematic Flow of Water in the Washington, D. C. Area



Total DC Solid Waste = 950 + 400 + 500 + 100 + 50 = 2000 tons/day

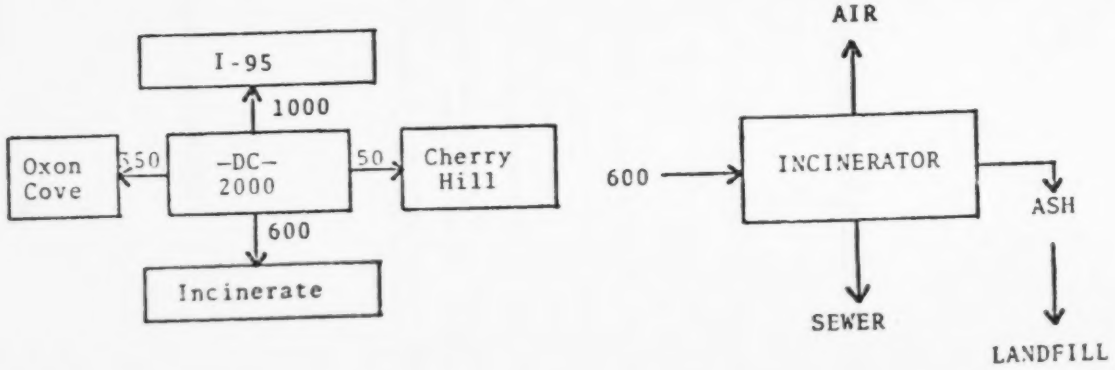


Figure 2. Solid Waste Movement in the Washington, D. C. Area

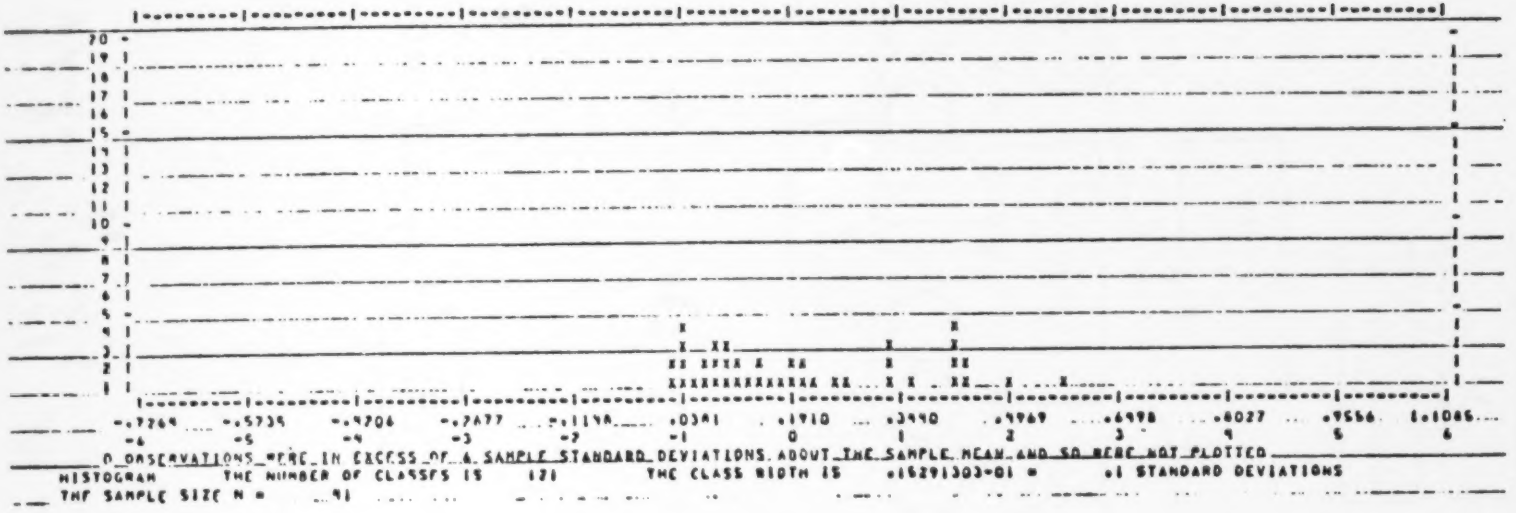

-.7269 -.5735 -.4706 -.2677 -.1198 .0341 .1910 .3990 .6969 .8027 .9556 1.1086
-4 -3 -2 -1 0 1 2 3 4 5 6
0 OBSERVATIONS WERE IN EXCESS OF 4 SAMPLE STANDARD DEVIATIONS ABOUT THE SAMPLE MEAN AND SO WERE NOT PLOTTED
HISTOGRAM THE NUMBER OF CLASSES IS 12 THE CLASS WIDTH IS .1529303-01 = .1 STANDARD DEVIATIONS
THE SAMPLE SIZE N = 91

Figure 3. Histogram for Lead on Air Filters

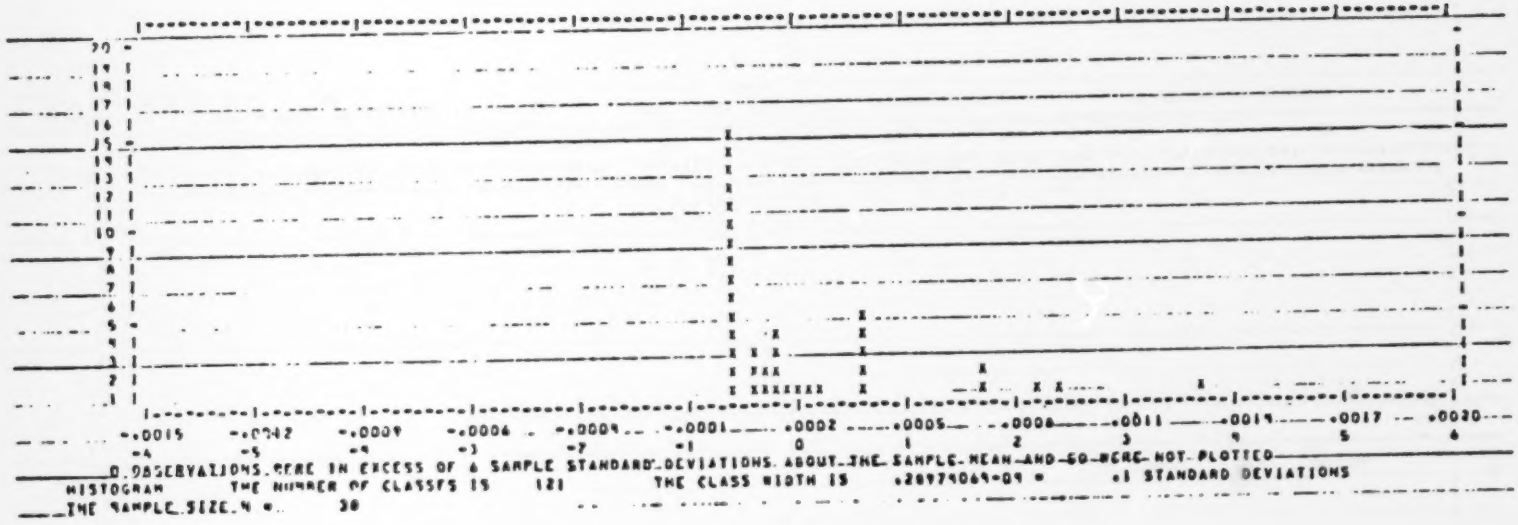


Figure 4. Histogram for Mercury in Drinking Water

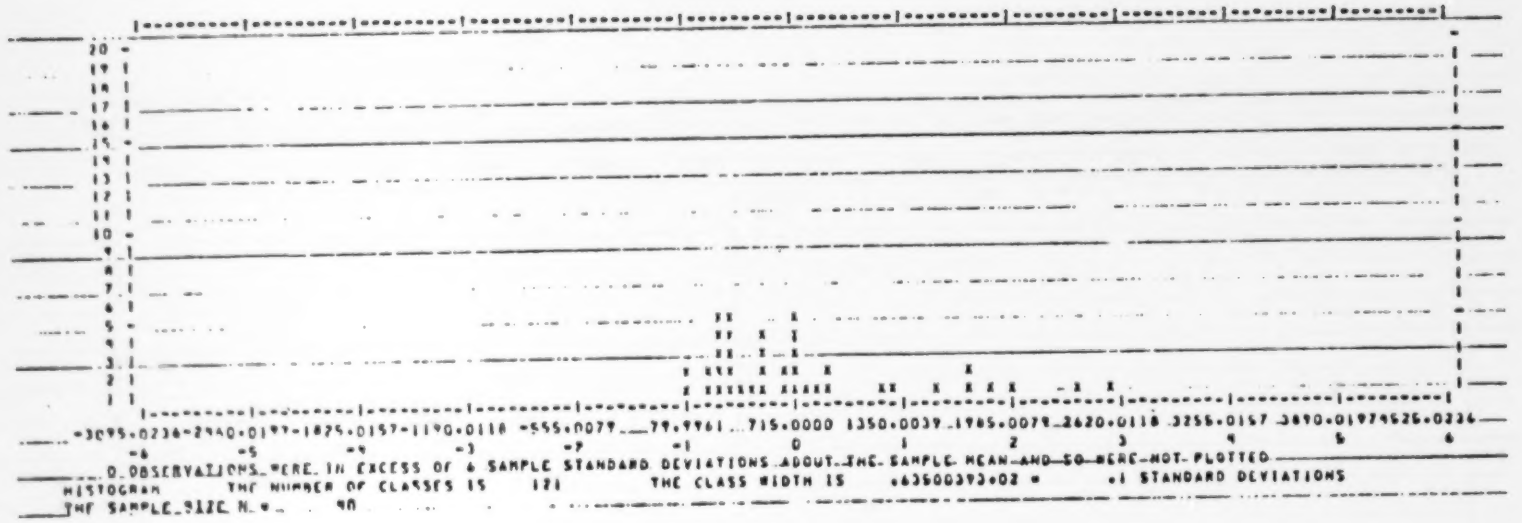


Figure 5. Histogram for Lead in Street Dust

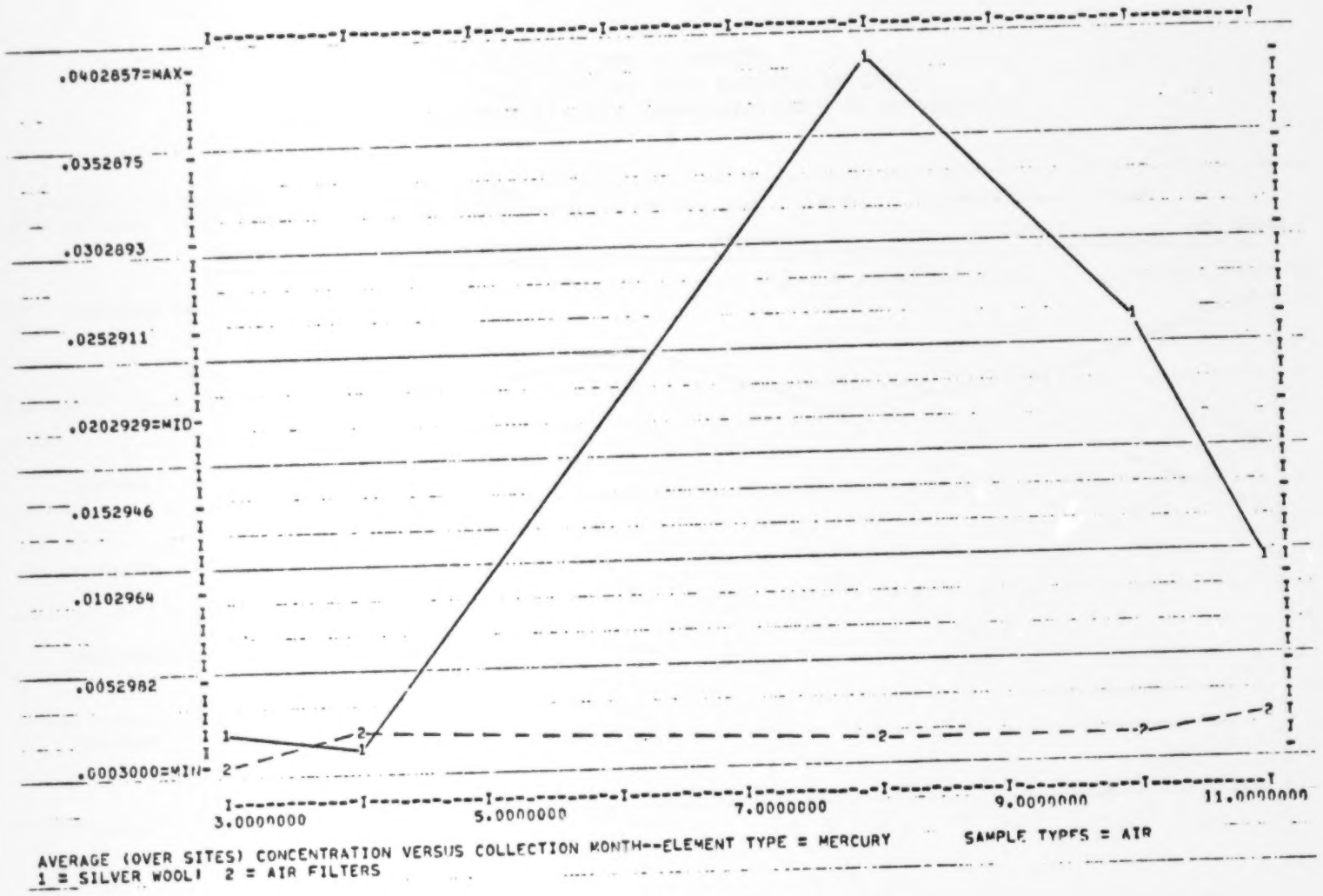


Figure 6. Monthly Average Concentrations of Mercury in Air Plotted With Respect to Time. (Numerical Value is Month)

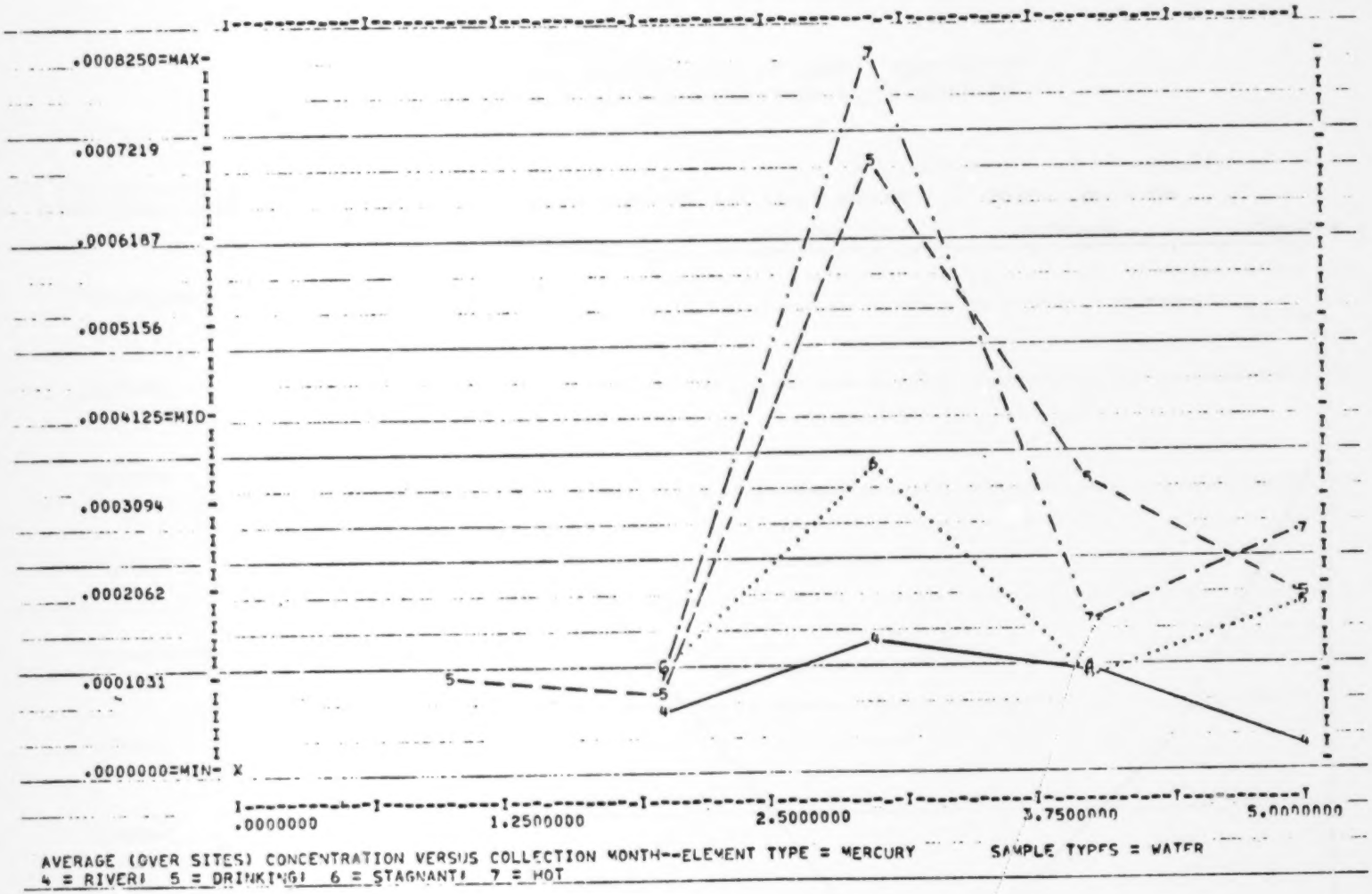


Figure 7. Monthly Average Concentrations of Mercury in Water Plotted with Respect to Time. (Numerical Value is Month)

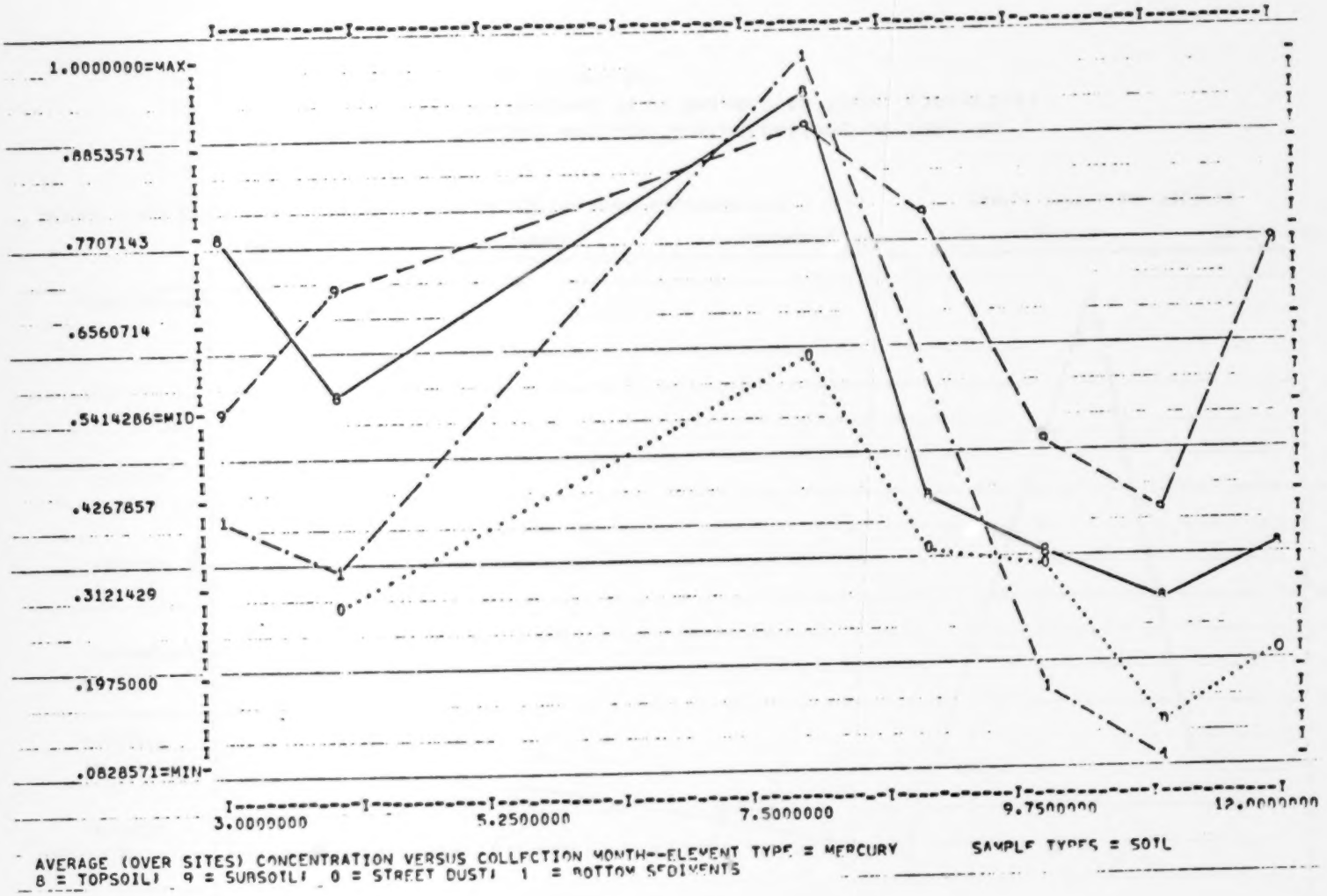


Figure 8. Monthly Average Concentrations of Mercury in Soil Plotted With Respect to Time. (Numerical Value is Month)

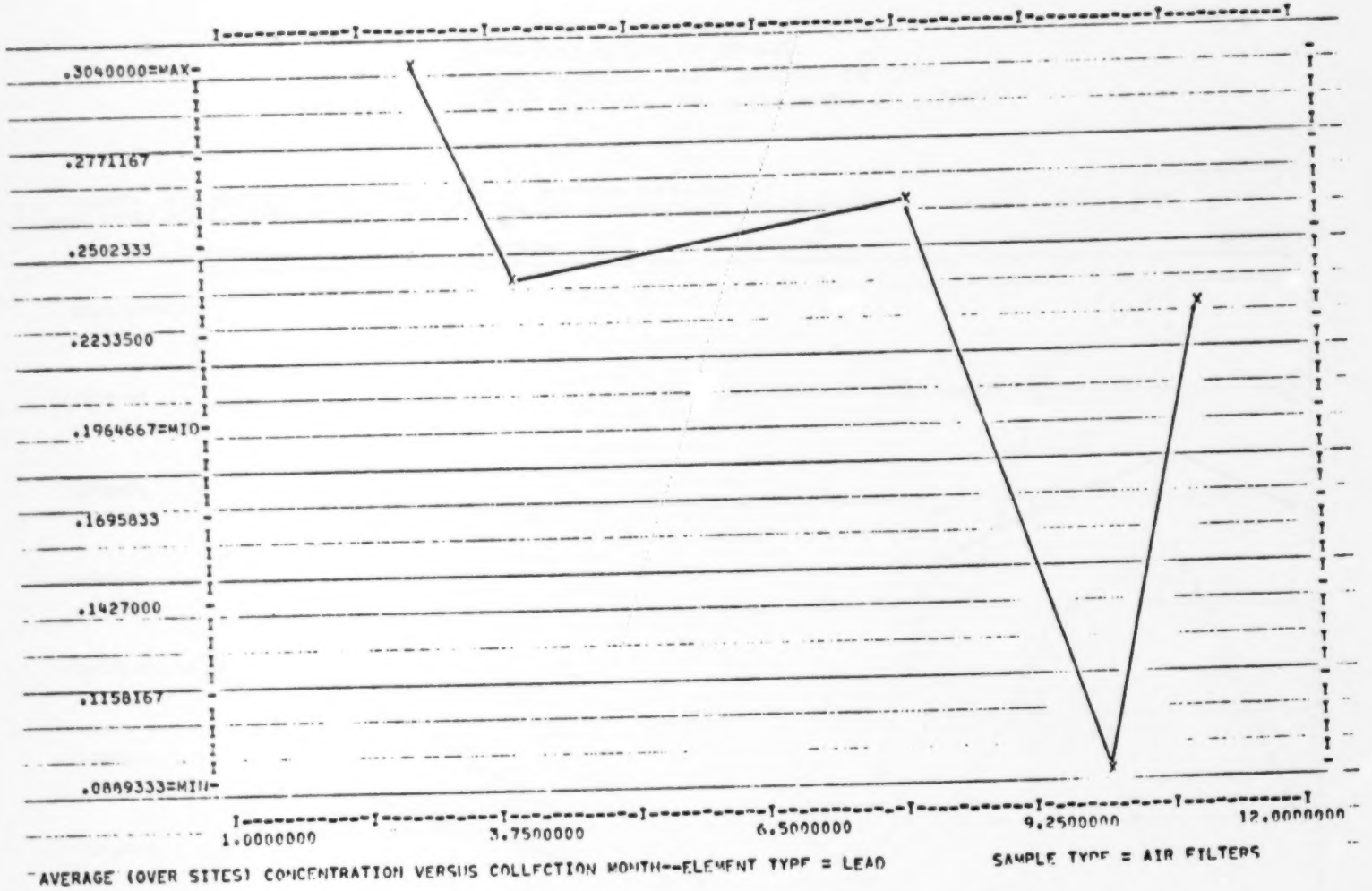


Figure 9. Monthly Average Concentrations of Lead in Air Plotted With Respect to Time. (Numerical Value is Month)

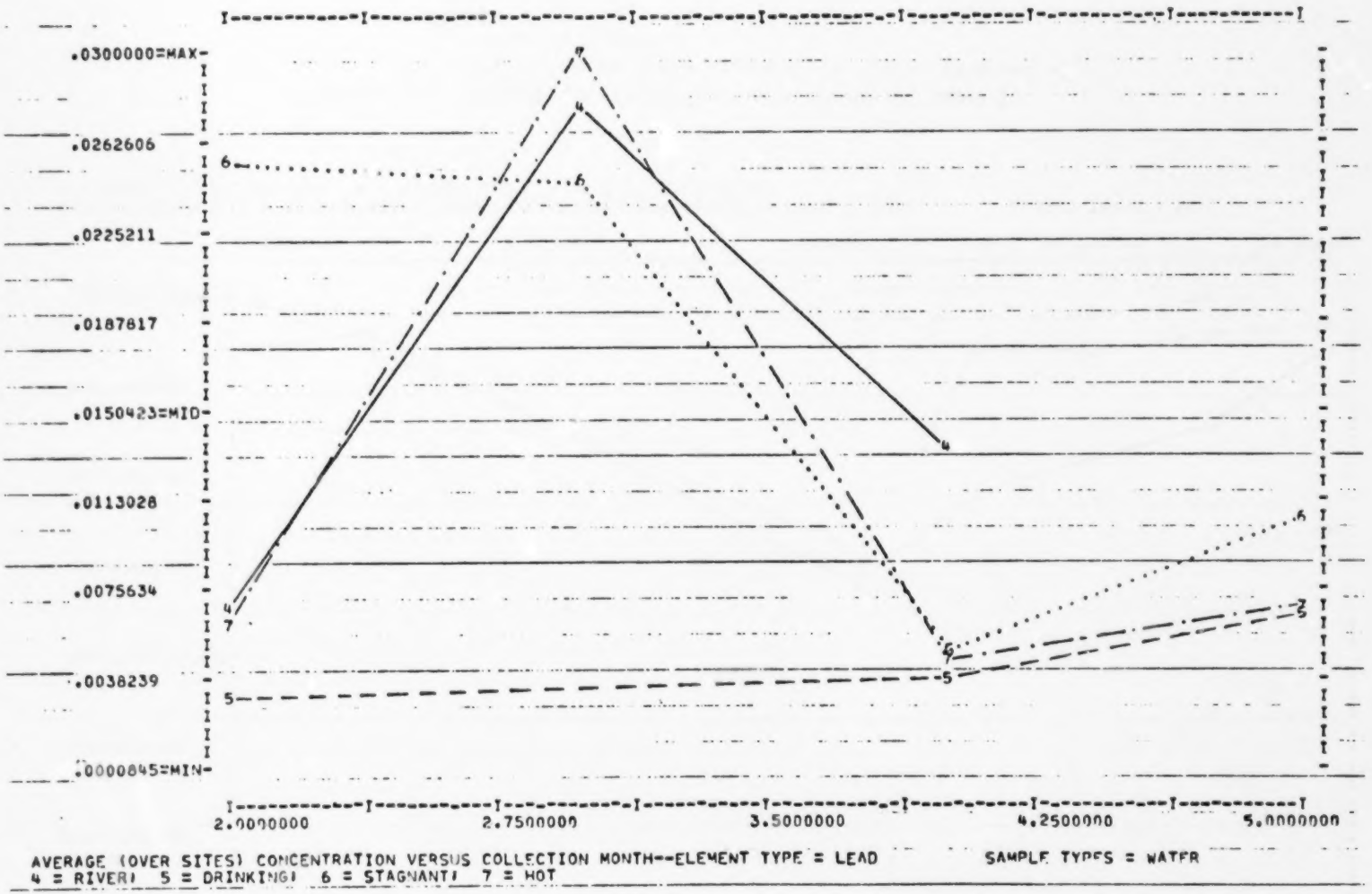


Figure 10. Monthly Average Concentrations of Lead in Water Plotted With Respect to Time. (Numerical Value is Month)

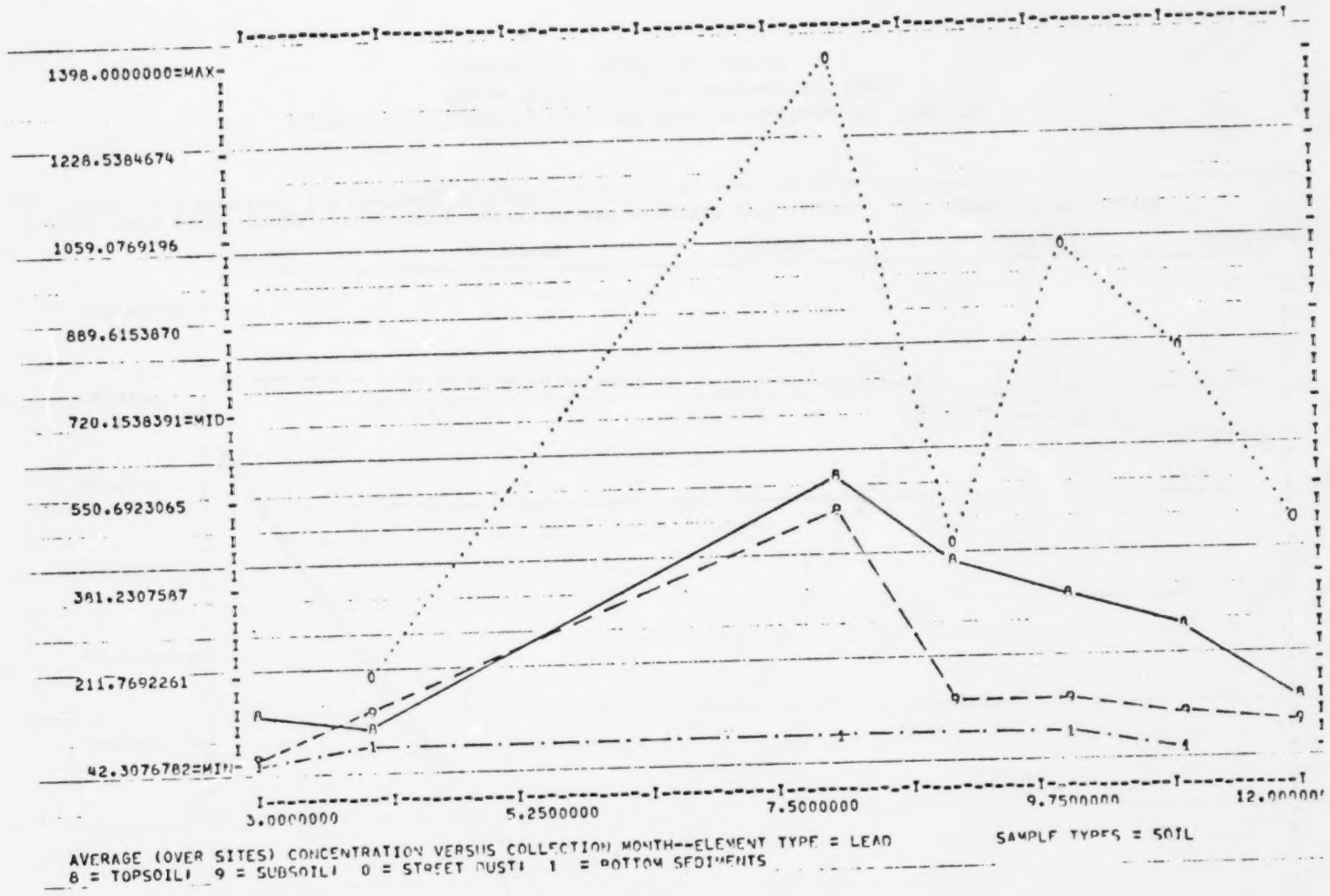


Figure 11. Monthly Average Concentrations of Lead in Soil Plotted With Respect to Time. (Numerical Value is Month)

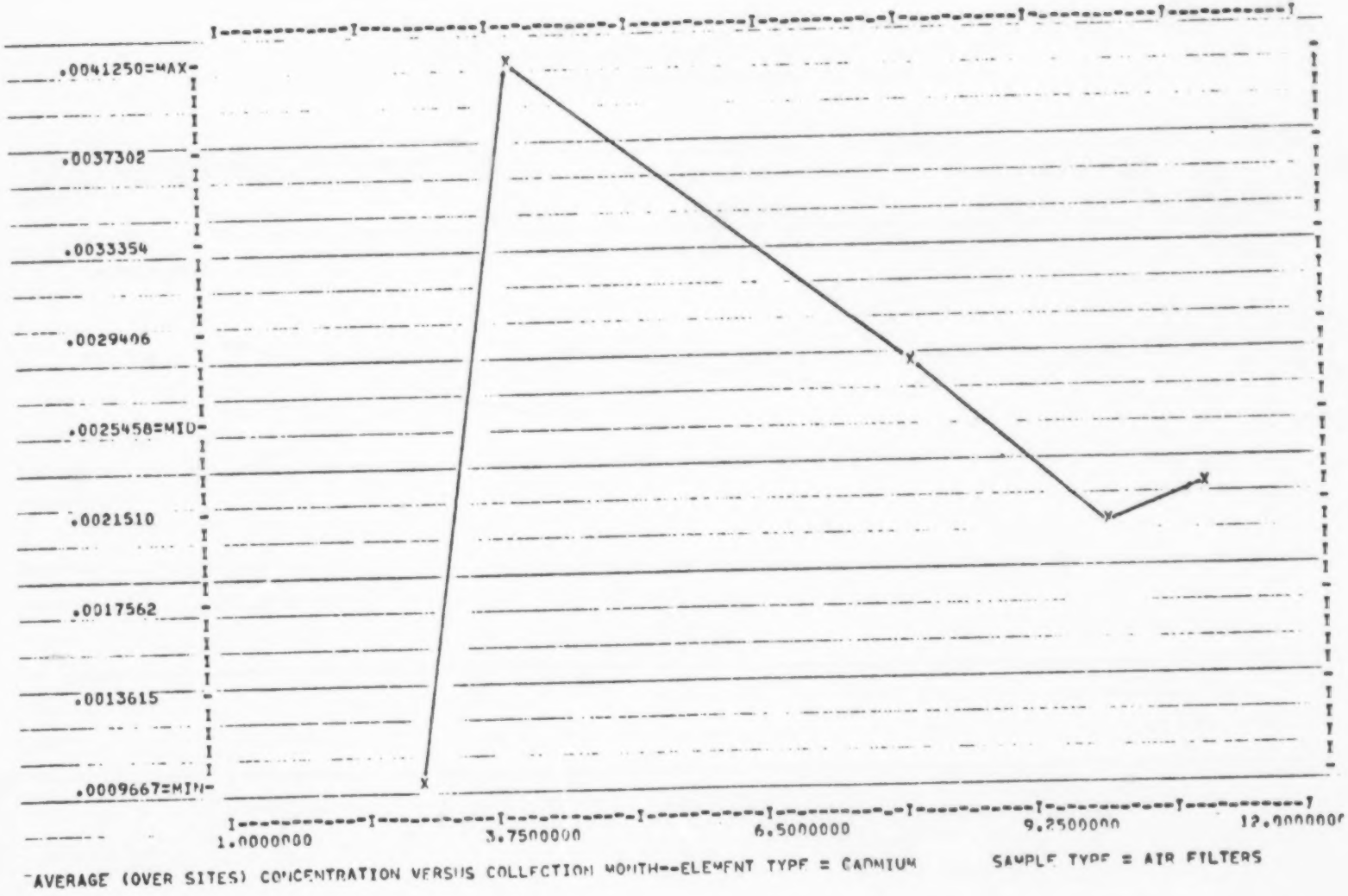


Figure 12. Monthly Average Concentrations of Cadmium in Air Plotted With Respect to Time. (Numerical Value is Month)

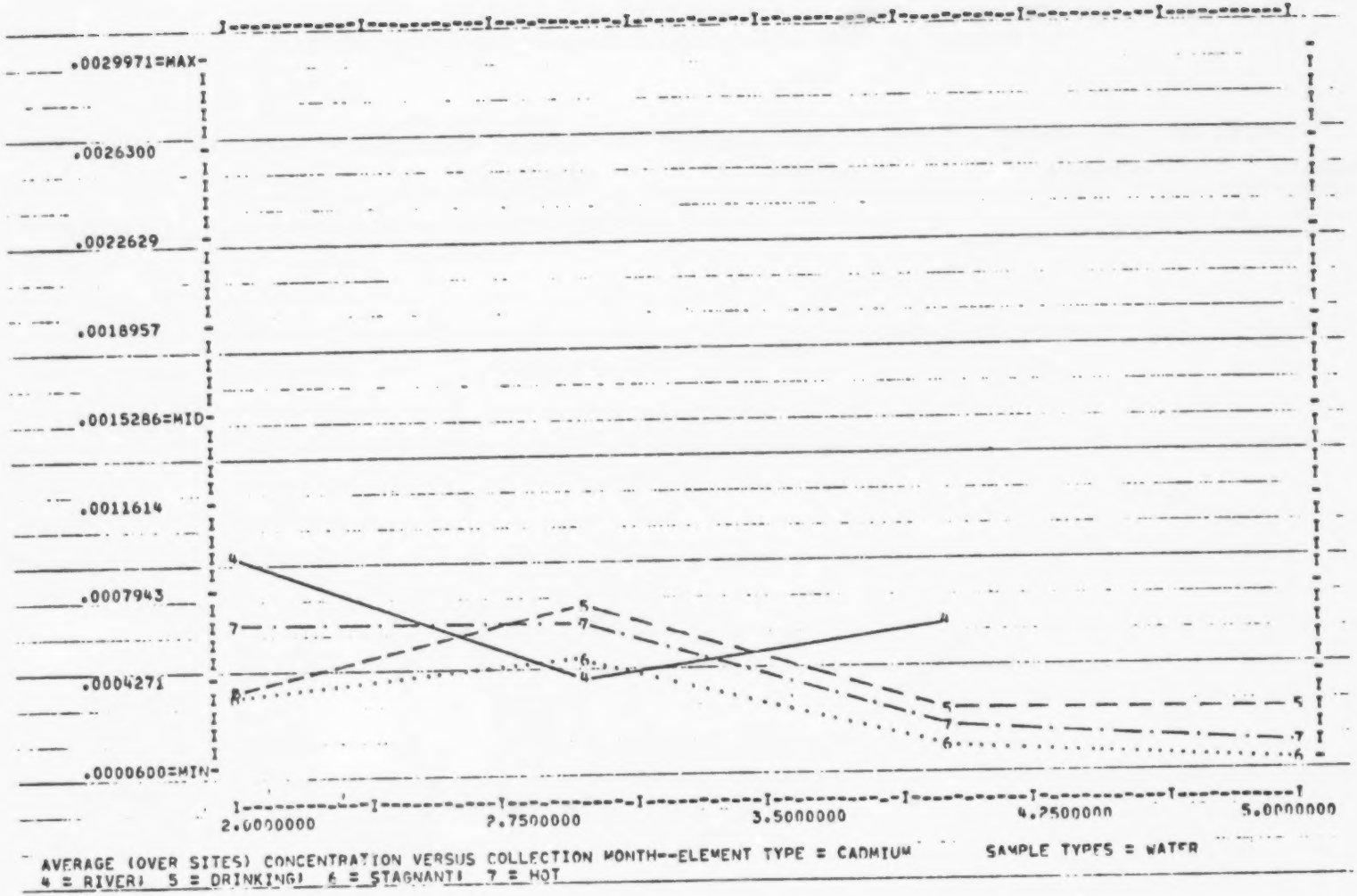


Figure 13. Monthly Average Concentrations of Cadmium in Water Plotted With Respect to Time. (Numerical Value is Month)

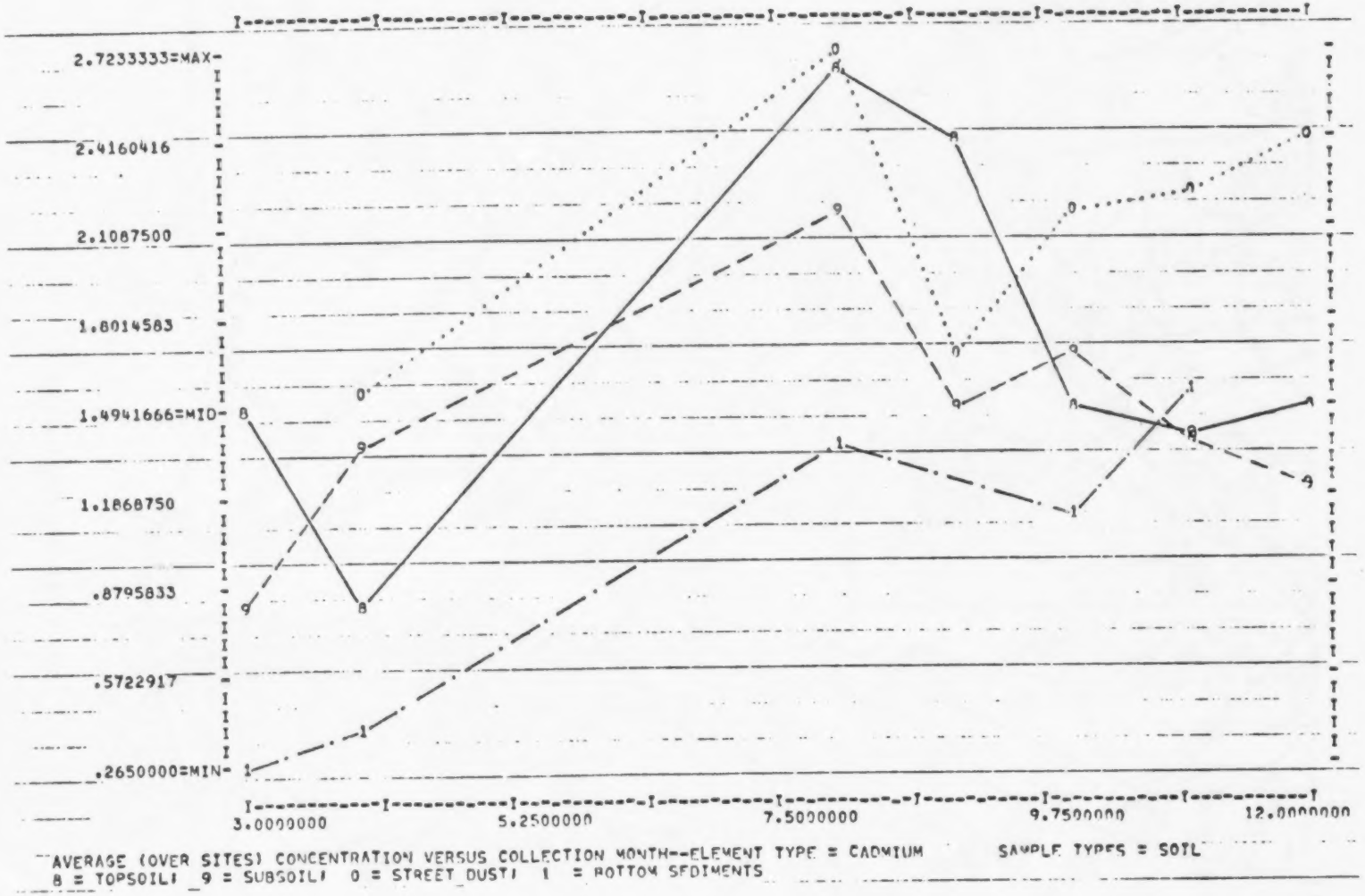
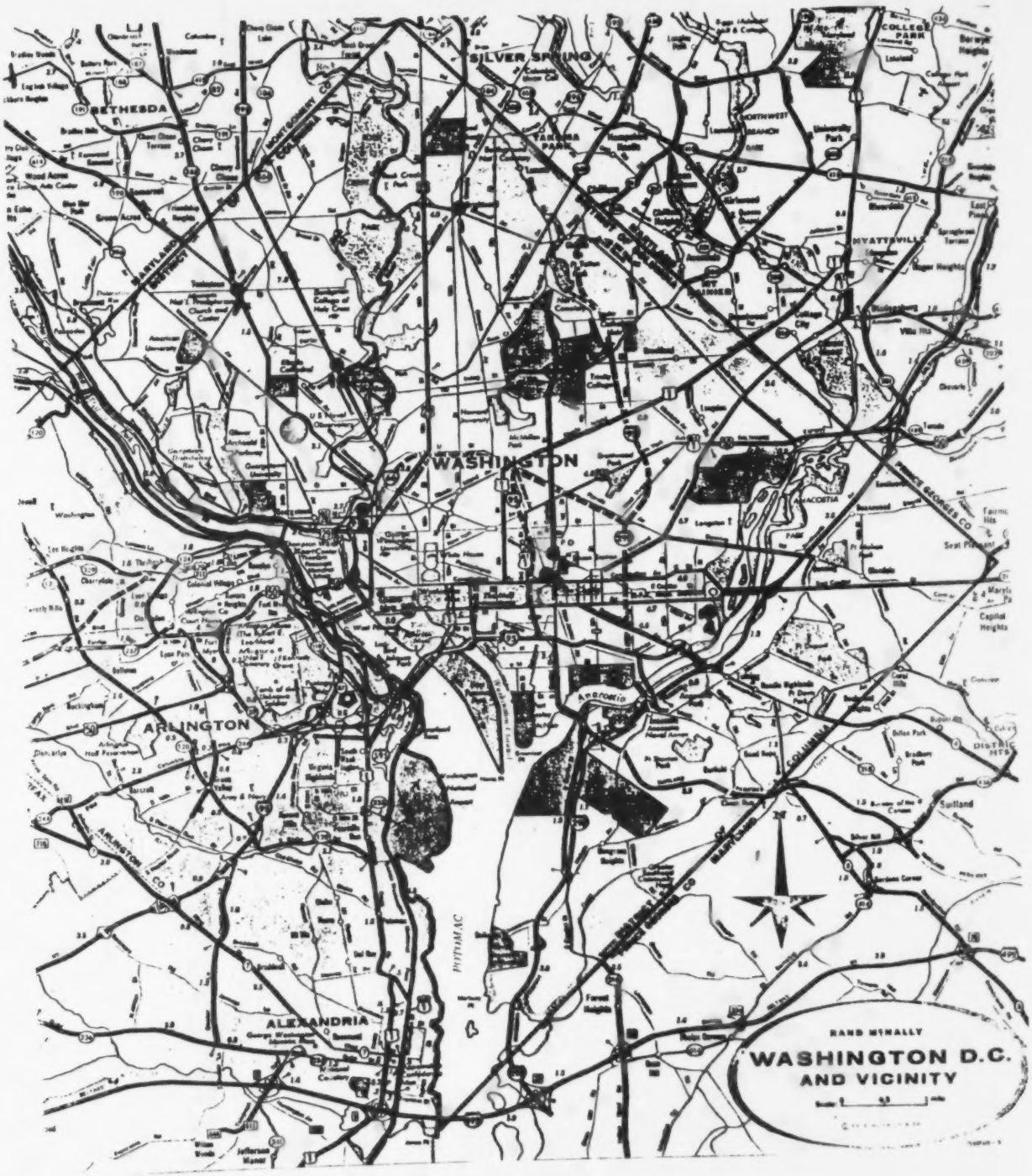
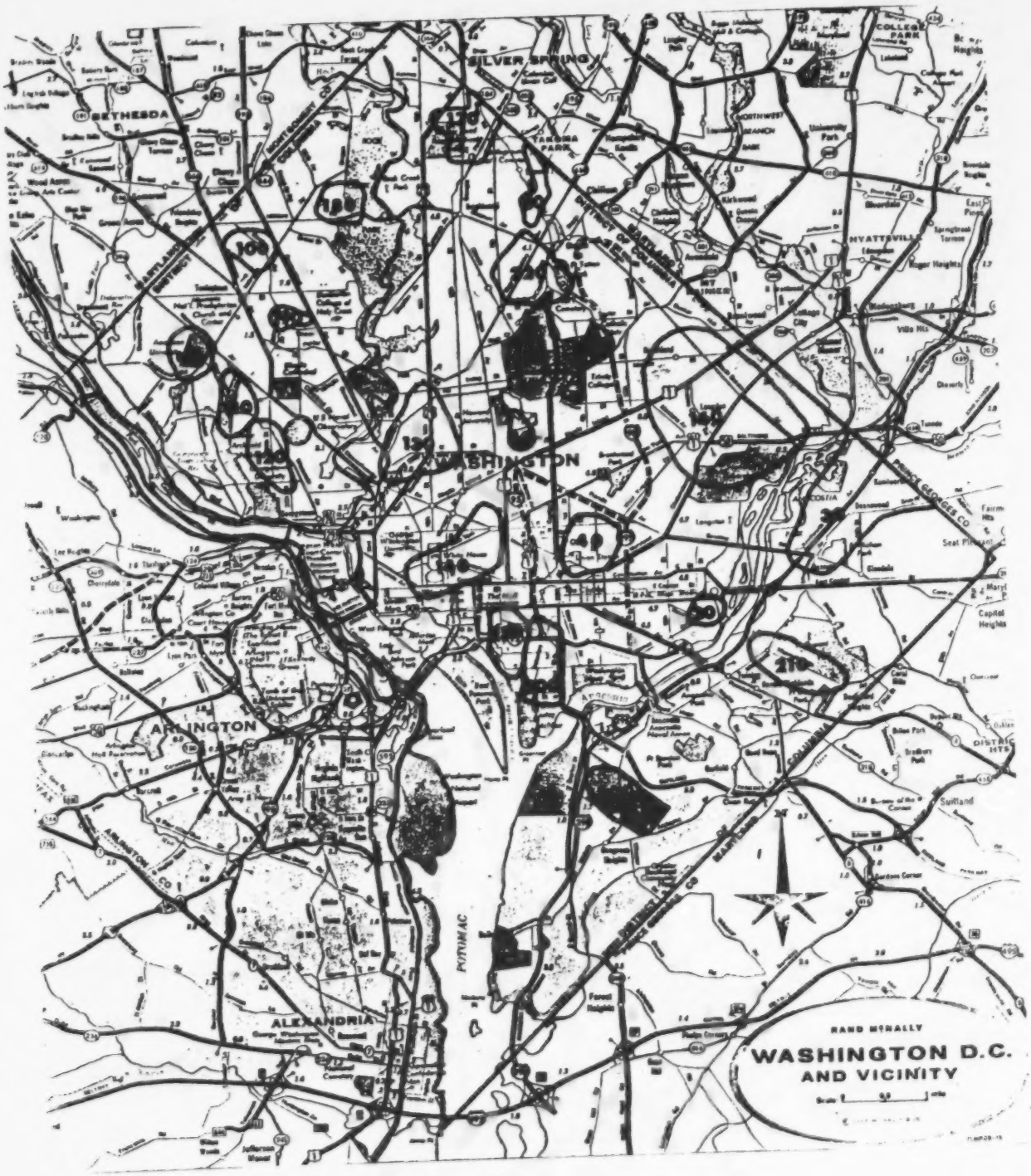


Figure 14. Monthly Average Concentrations of Cadmium in Soil Plotted With Respect to Time. (Numerical Value is Month)



Map 1. Air Sampling Stations



Map 2. Sewer Coverage

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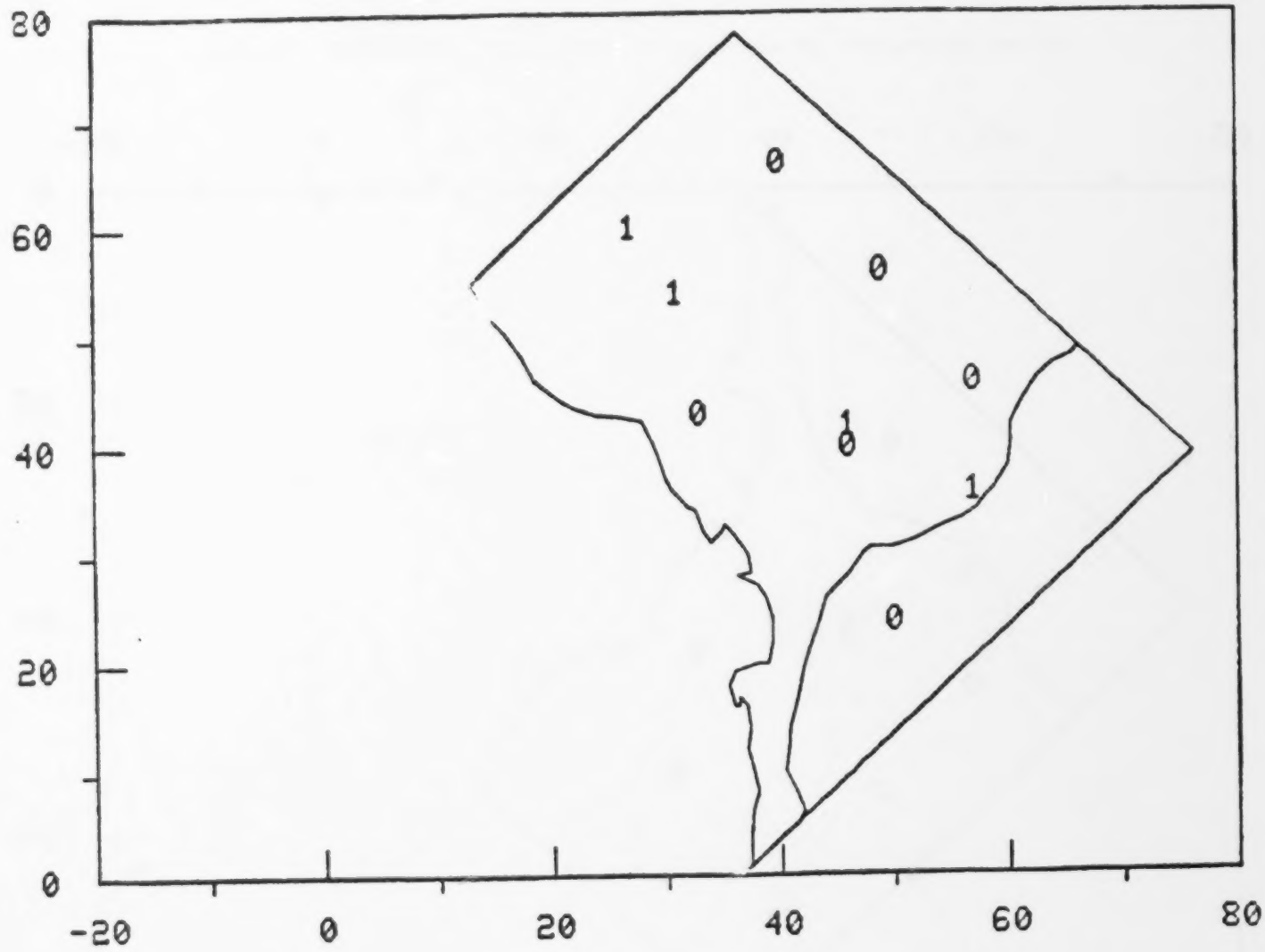
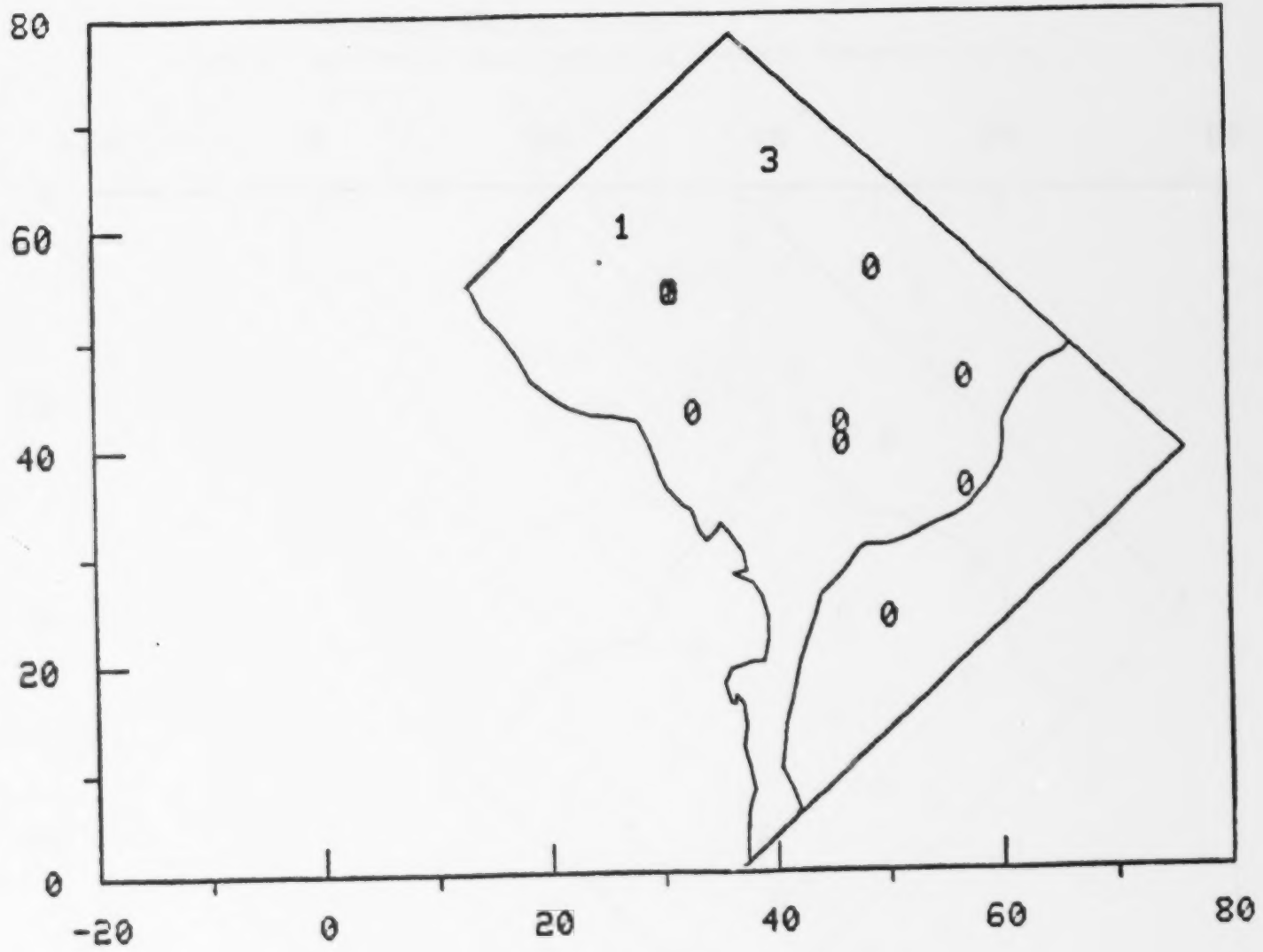
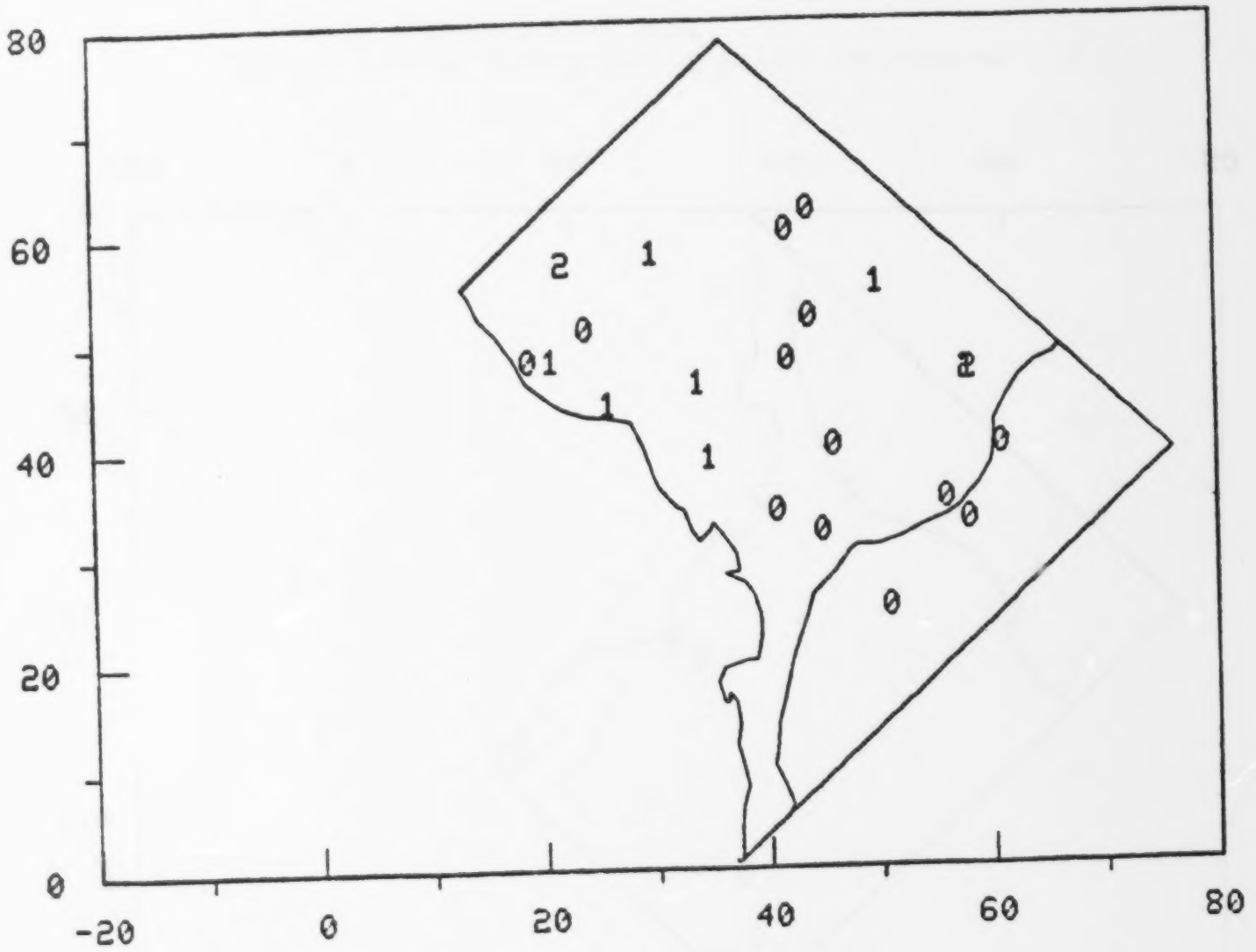
Map 3. Soil and Water Sampling Sites



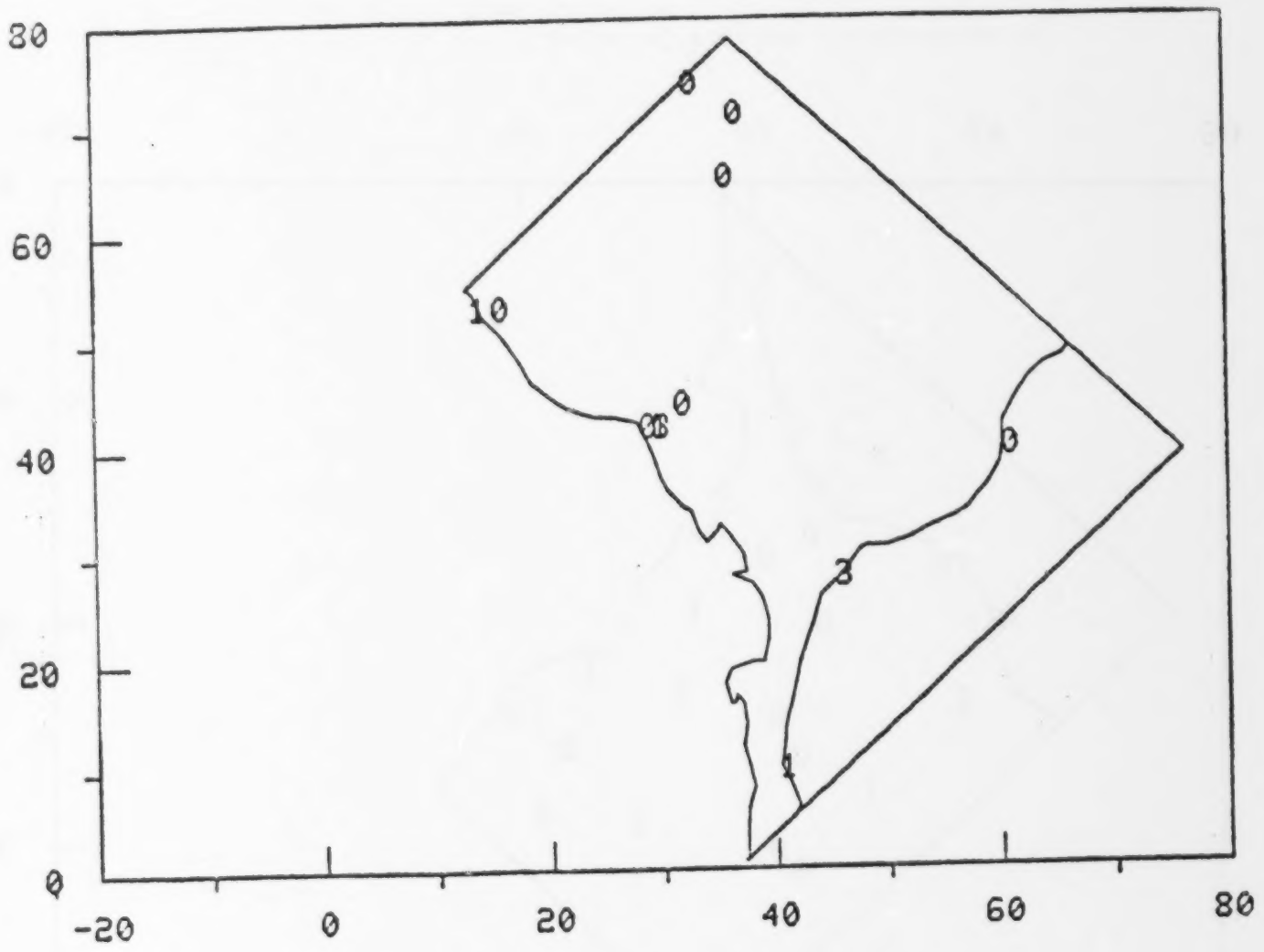
Map 4. Area-wide distribution of average concentration of elemental mercury in air



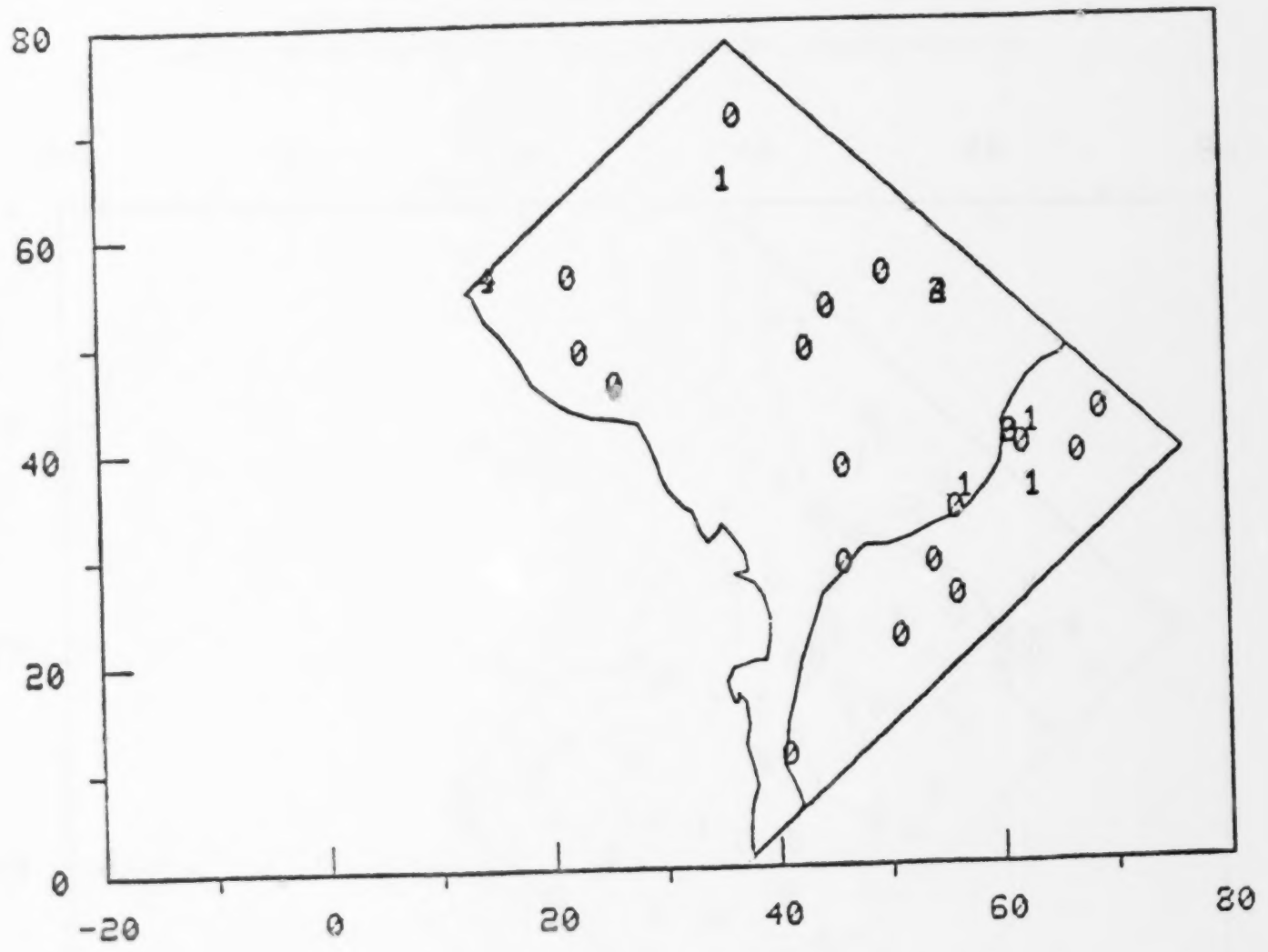
Map 5. Area-wide distribution of average concentration of particulate mercury in air.



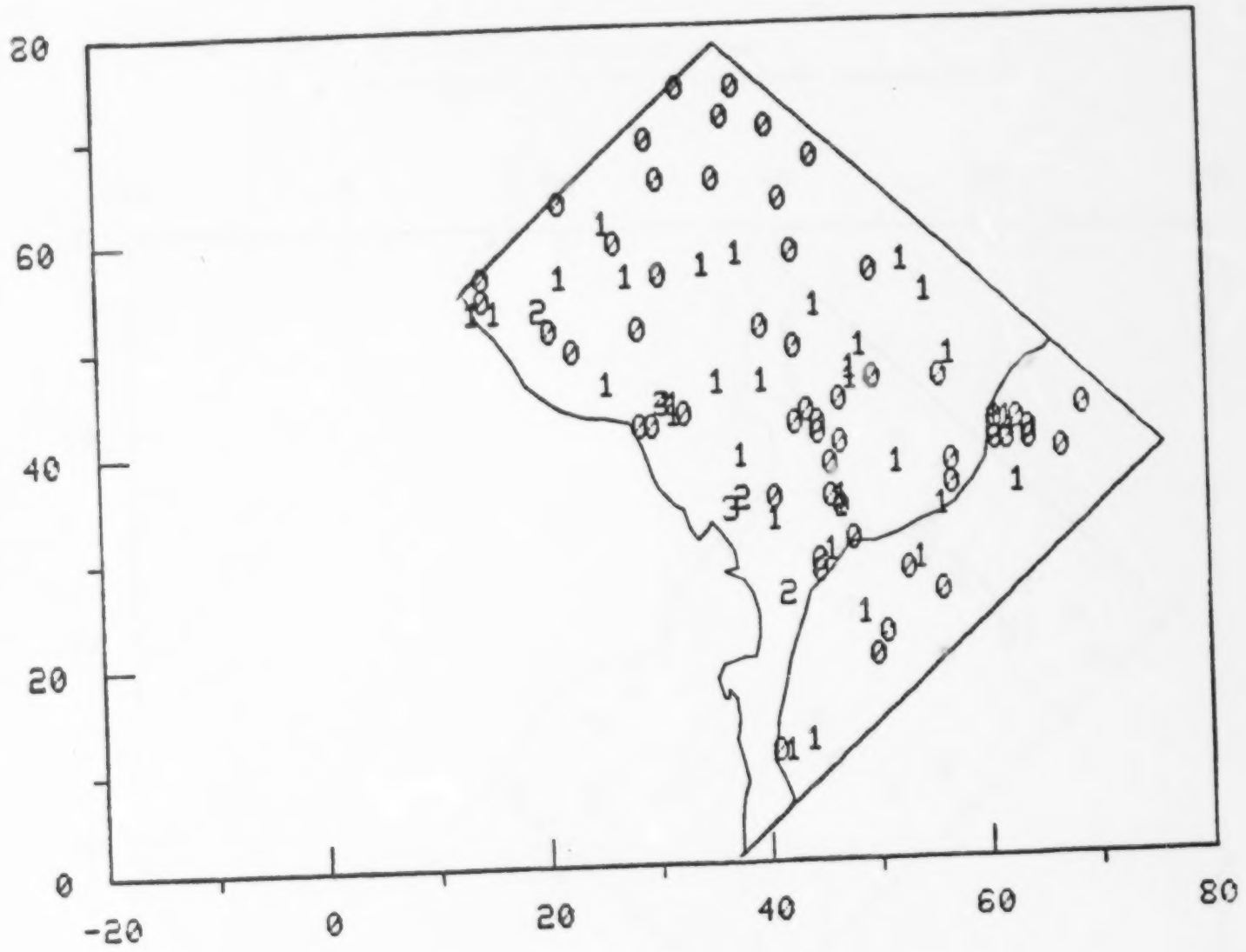
Map 6. Area-wide distribution of average concentration of mercury in sewer water



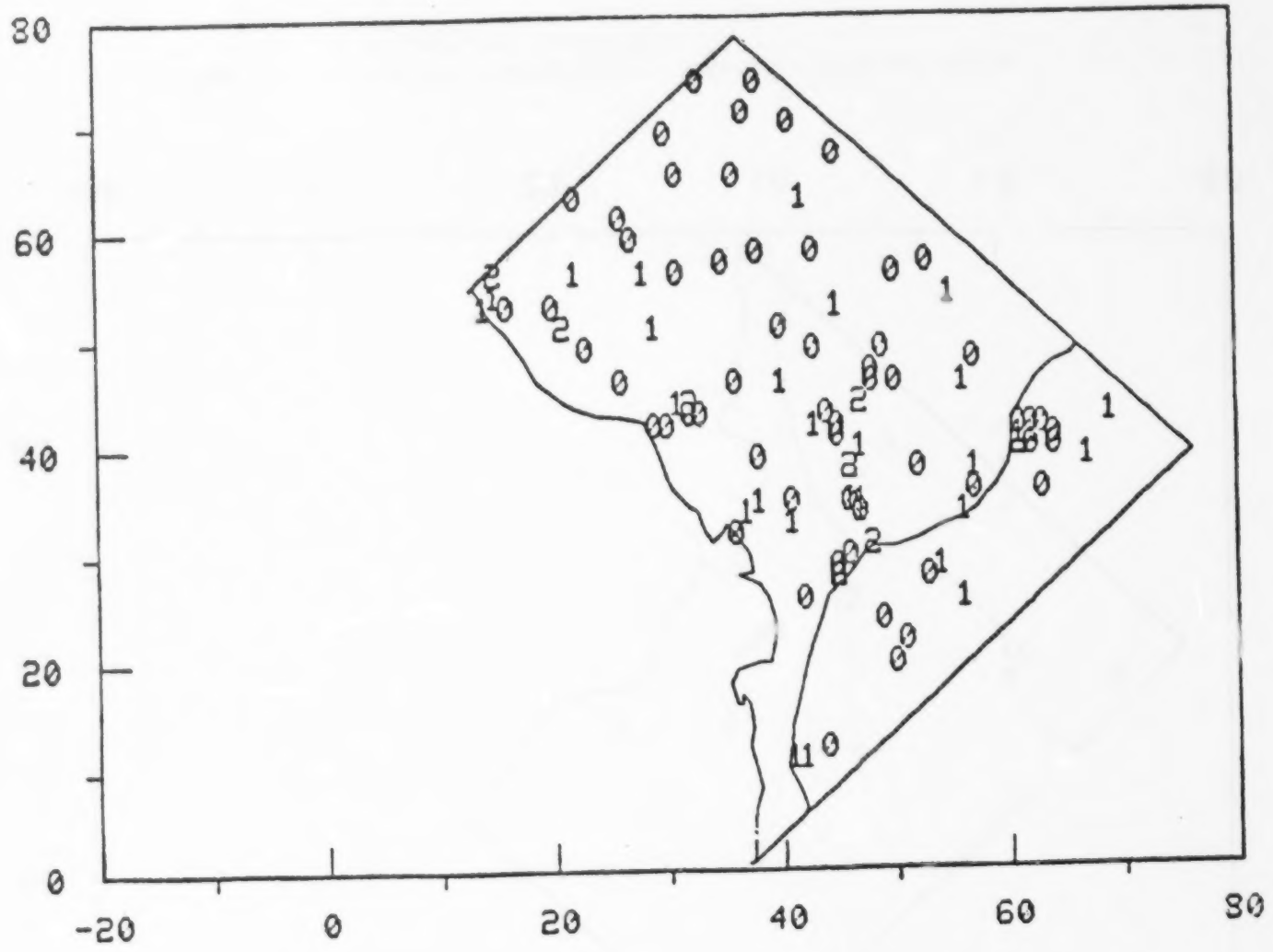
Map 7. Area-wide Distribution of Average Concentration of Mercury in River Water



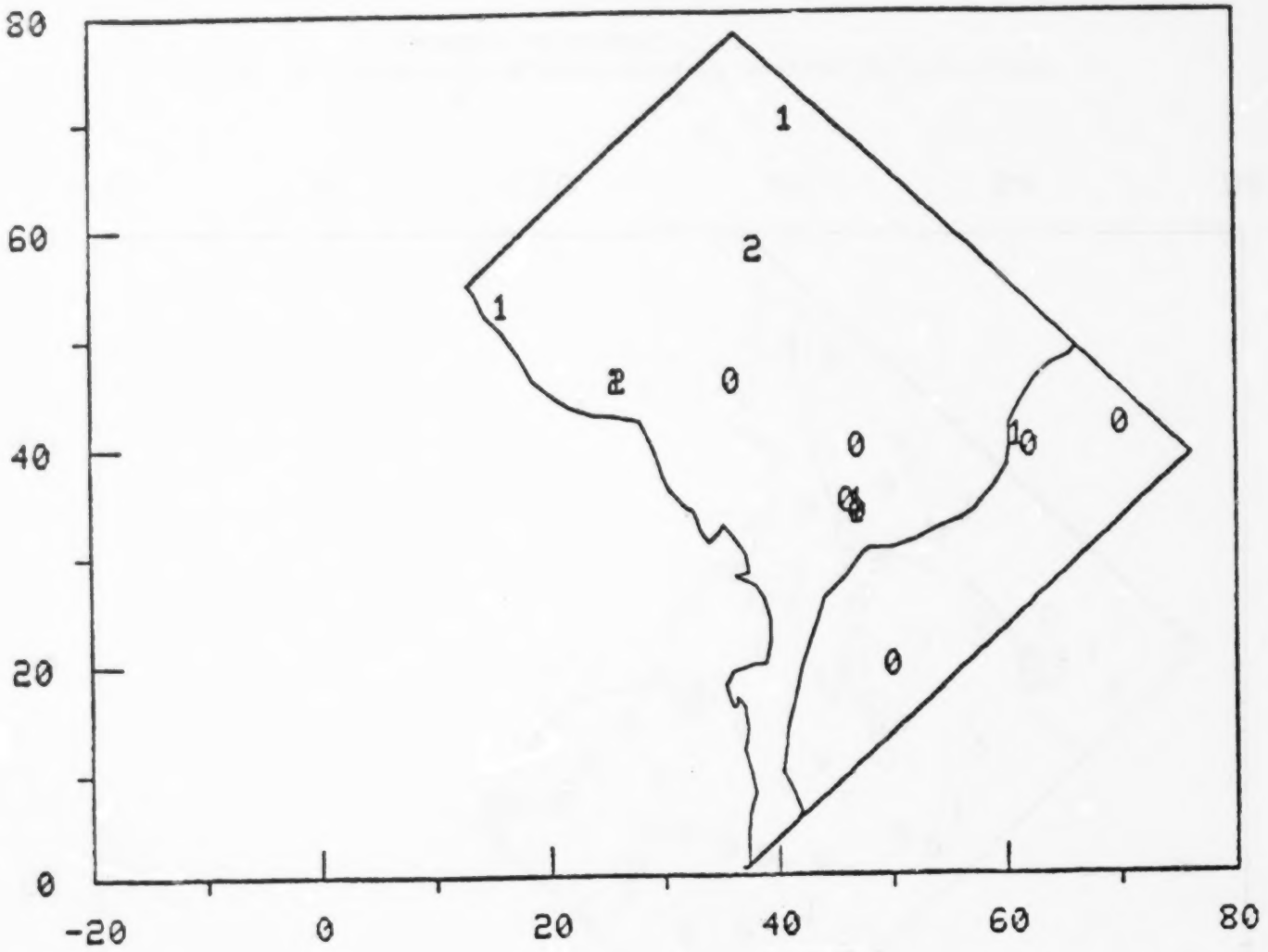
Map 8. Area-wide Distribution of Average Concentration of Mercury in Drinking Water



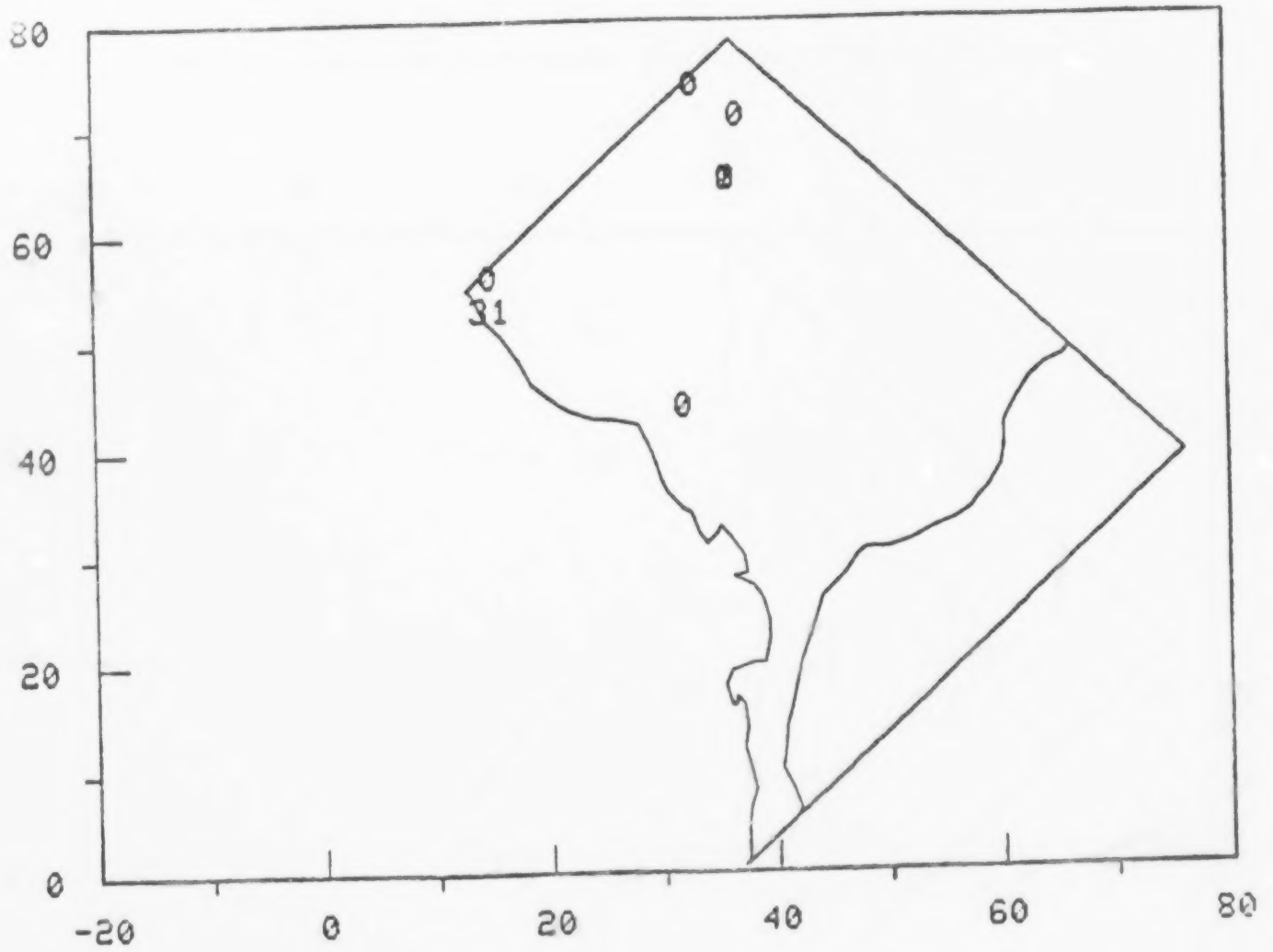
Map 9. Area-wide distribution of avérage concentration of mercury in topsoil



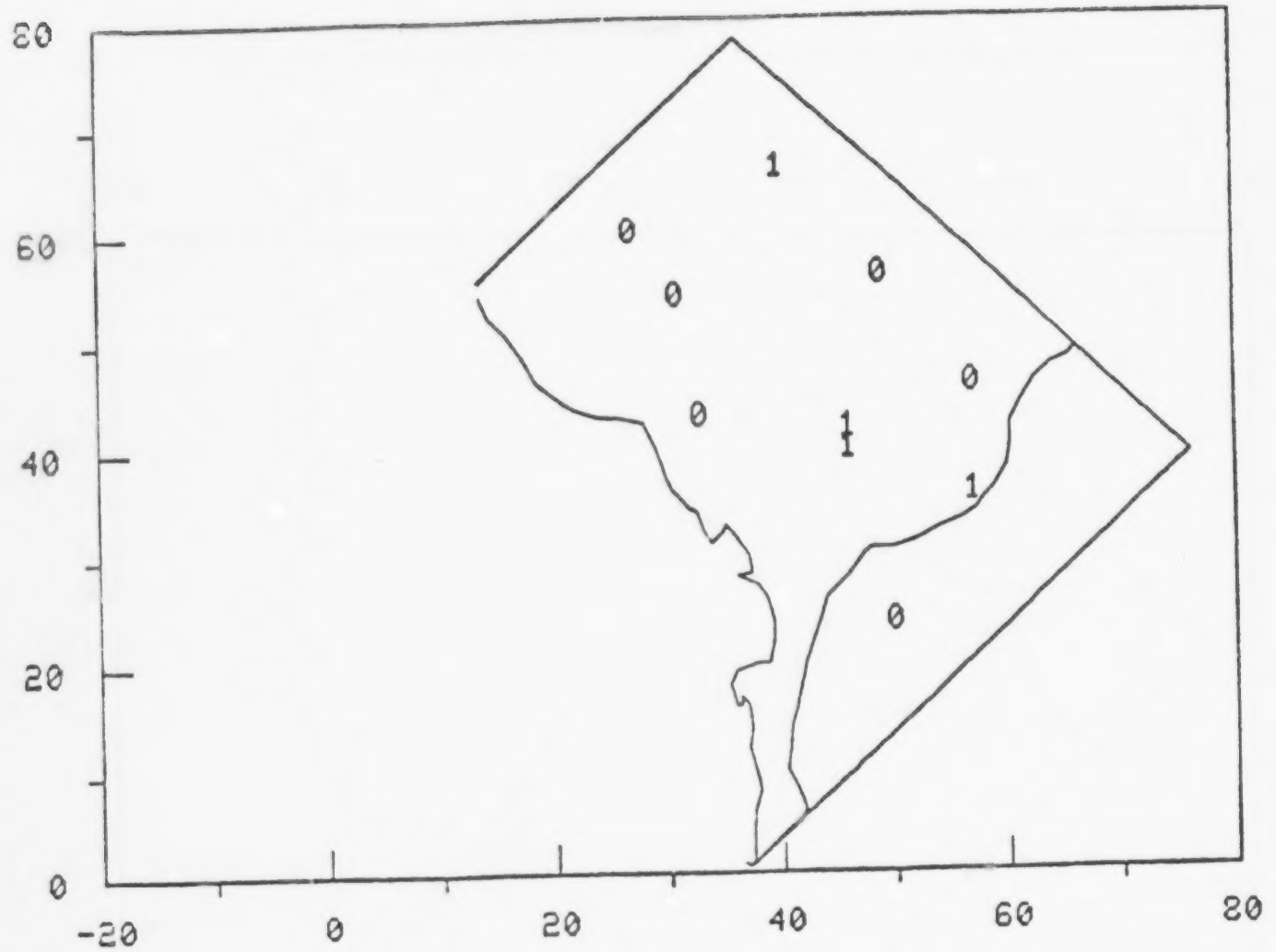
Map 10. Area-wide Distribution of Average Concentration of Mercury in Subsoil



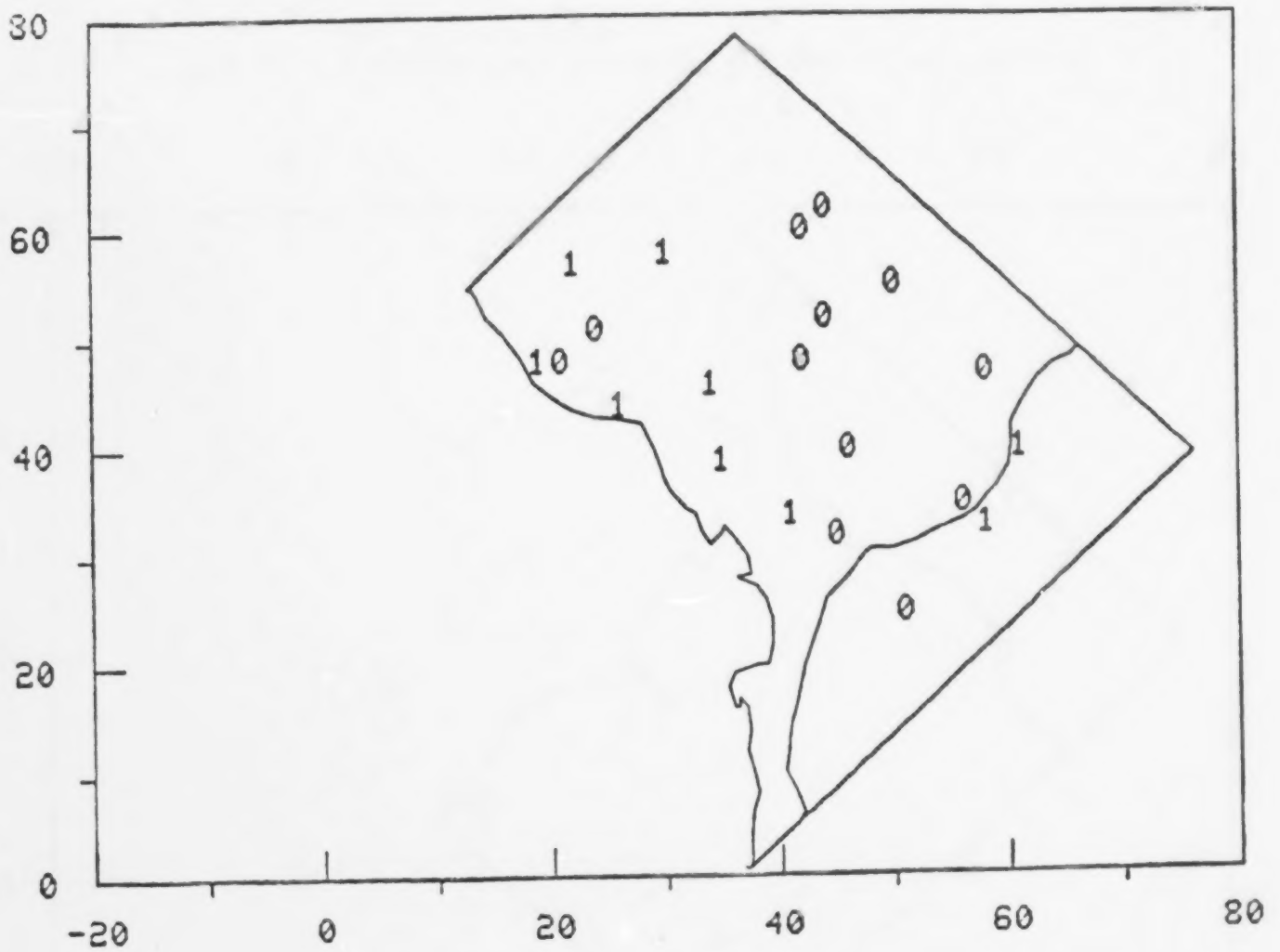
Map 11. Area-wide Distribution of Average Concentration of Mercury in Street Dust



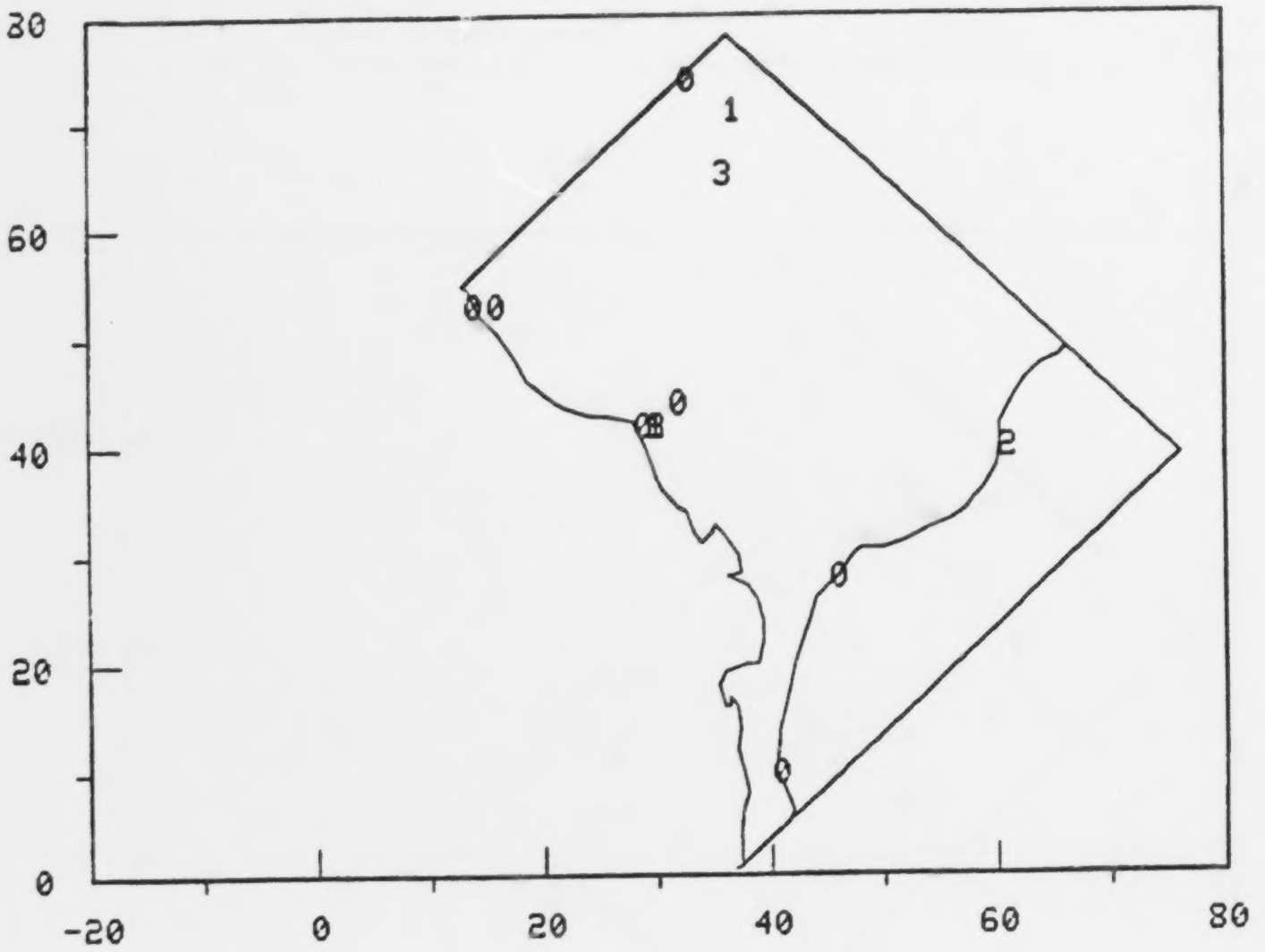
Map 12. Area-wide Distribution of Average Concentration of Mercury in Bottom Sediments



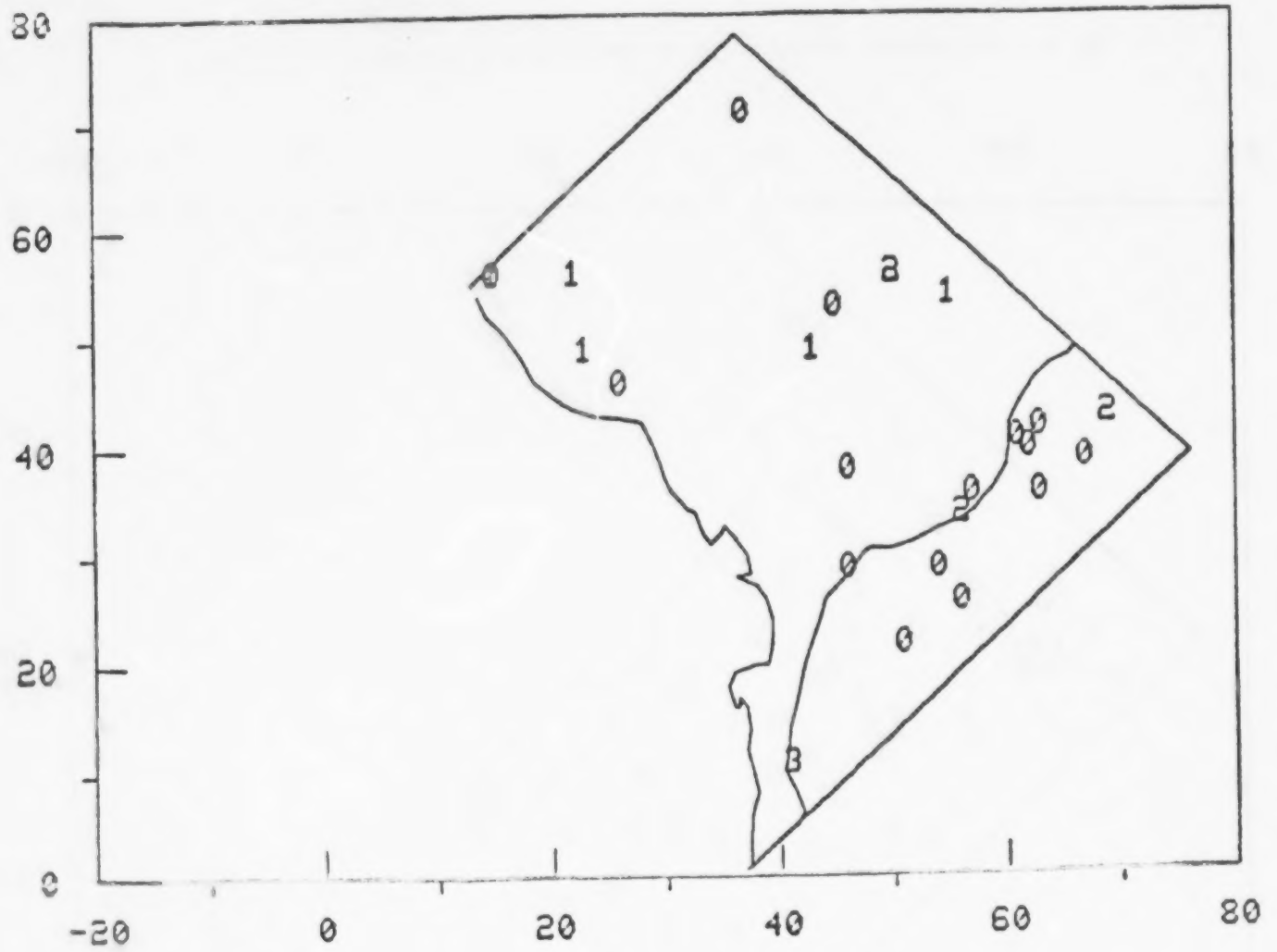
Map 13. Area-wide Distribution of Average Concentration of Lead in Air



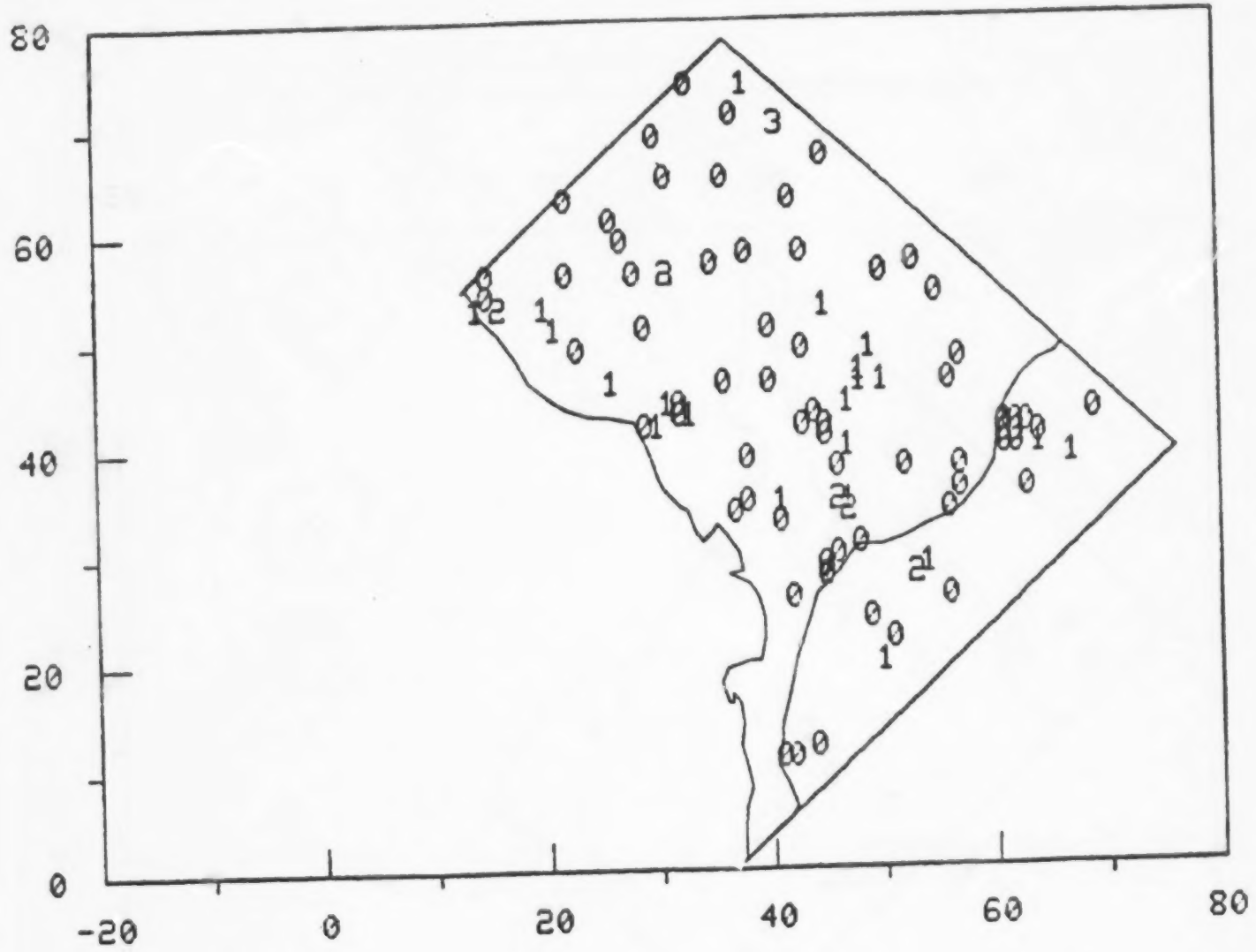
Map 14. Area-wide Distribution of Average Concentration of Lead in Sewer Water



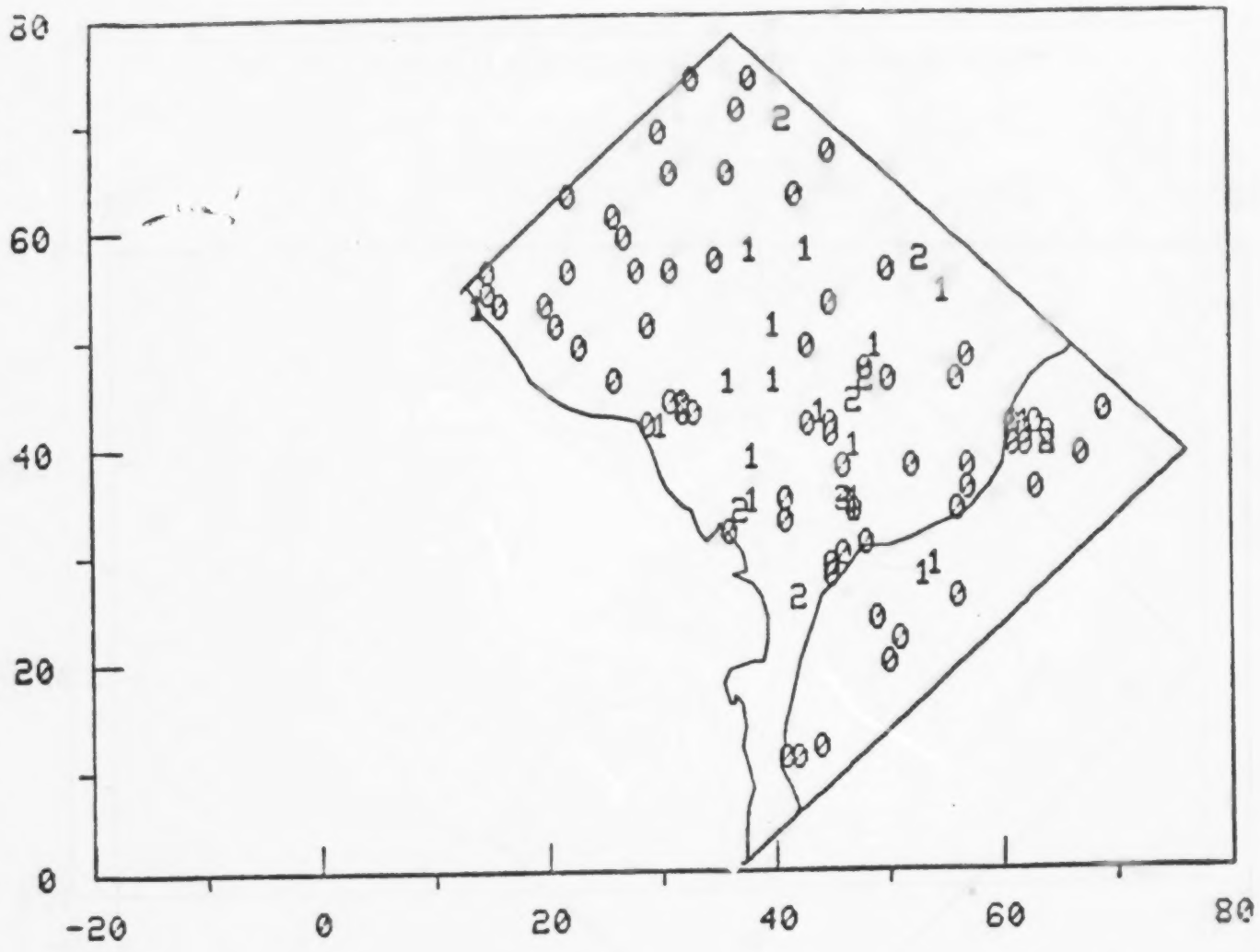
Map 15. Area-wide distribution of average concentration of lead in river water



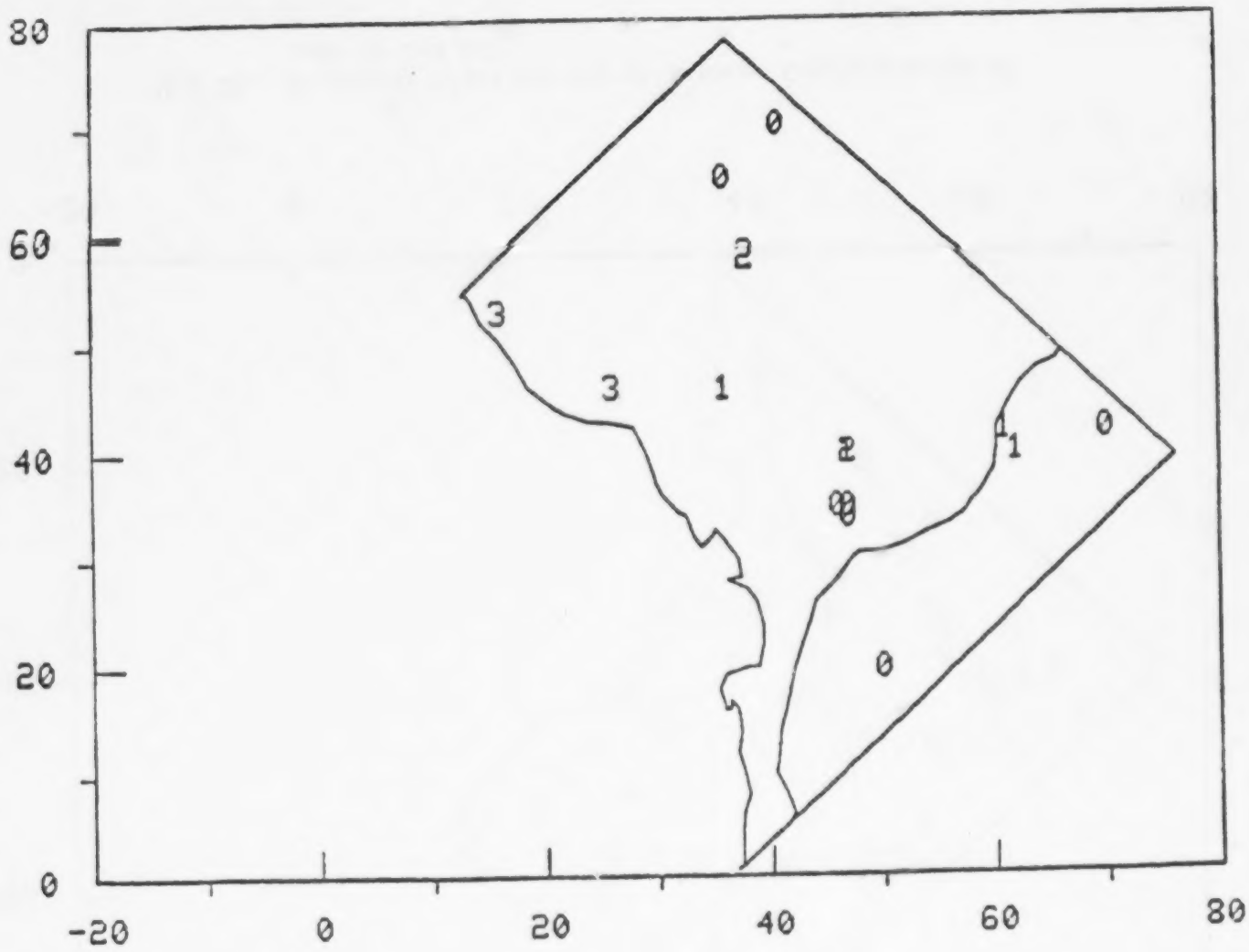
Map 16. Area-wide Distribution of Average Concentration of Lead in Drinking Water



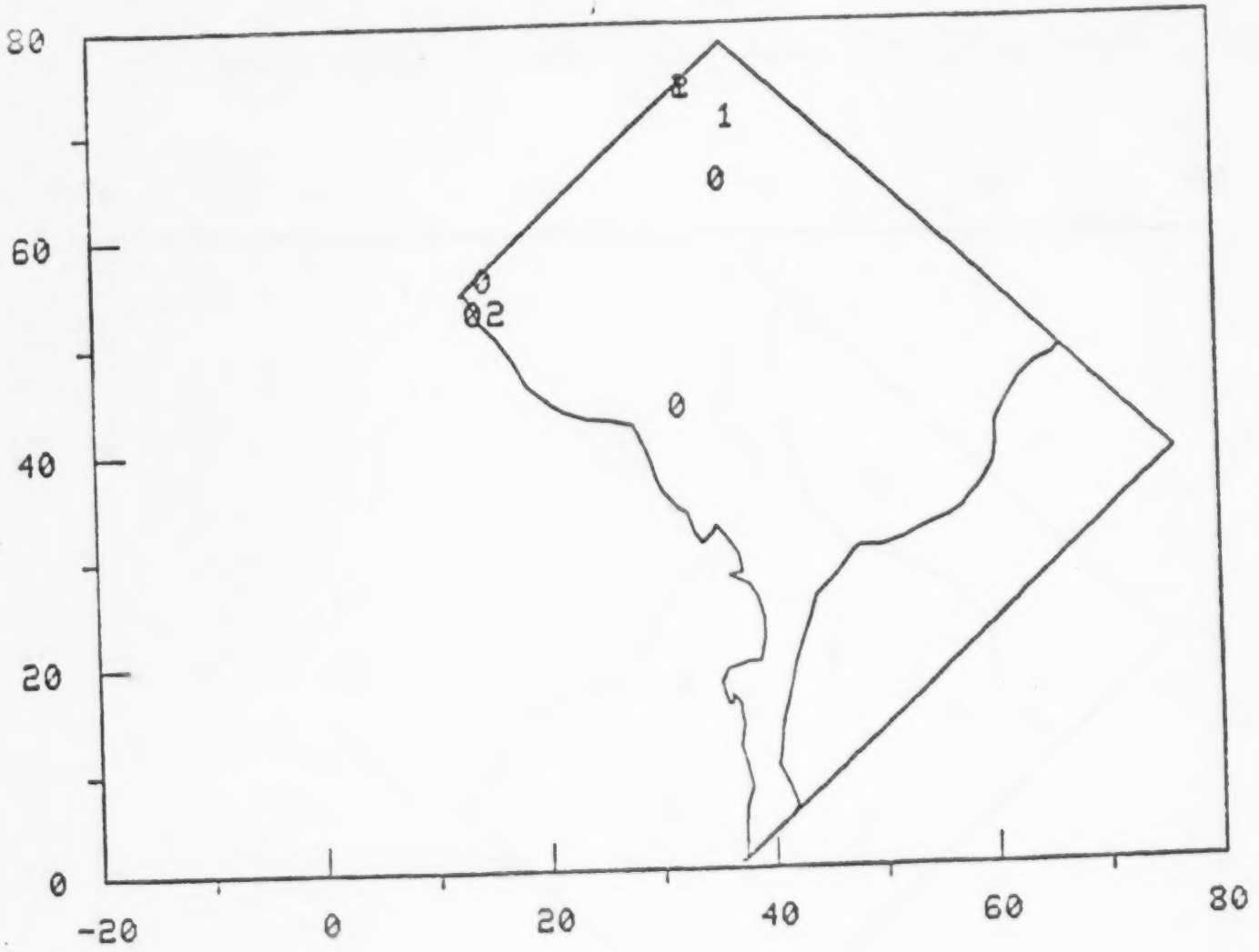
Map 17. Area-wide distribution of average concentration of lead in topsoil



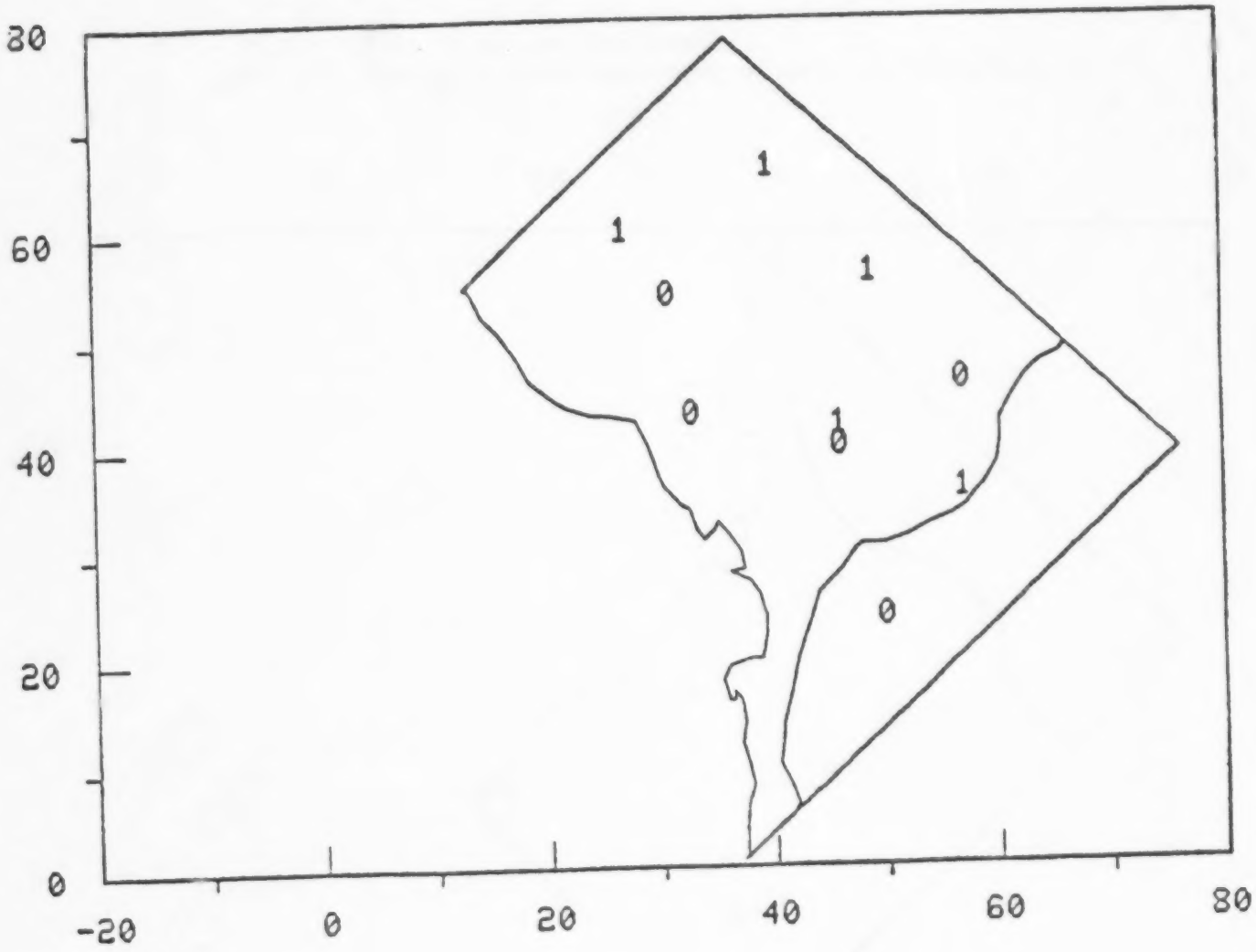
Map 18. Area-wide Distribution of Average Concentration of Lead in Subsoil



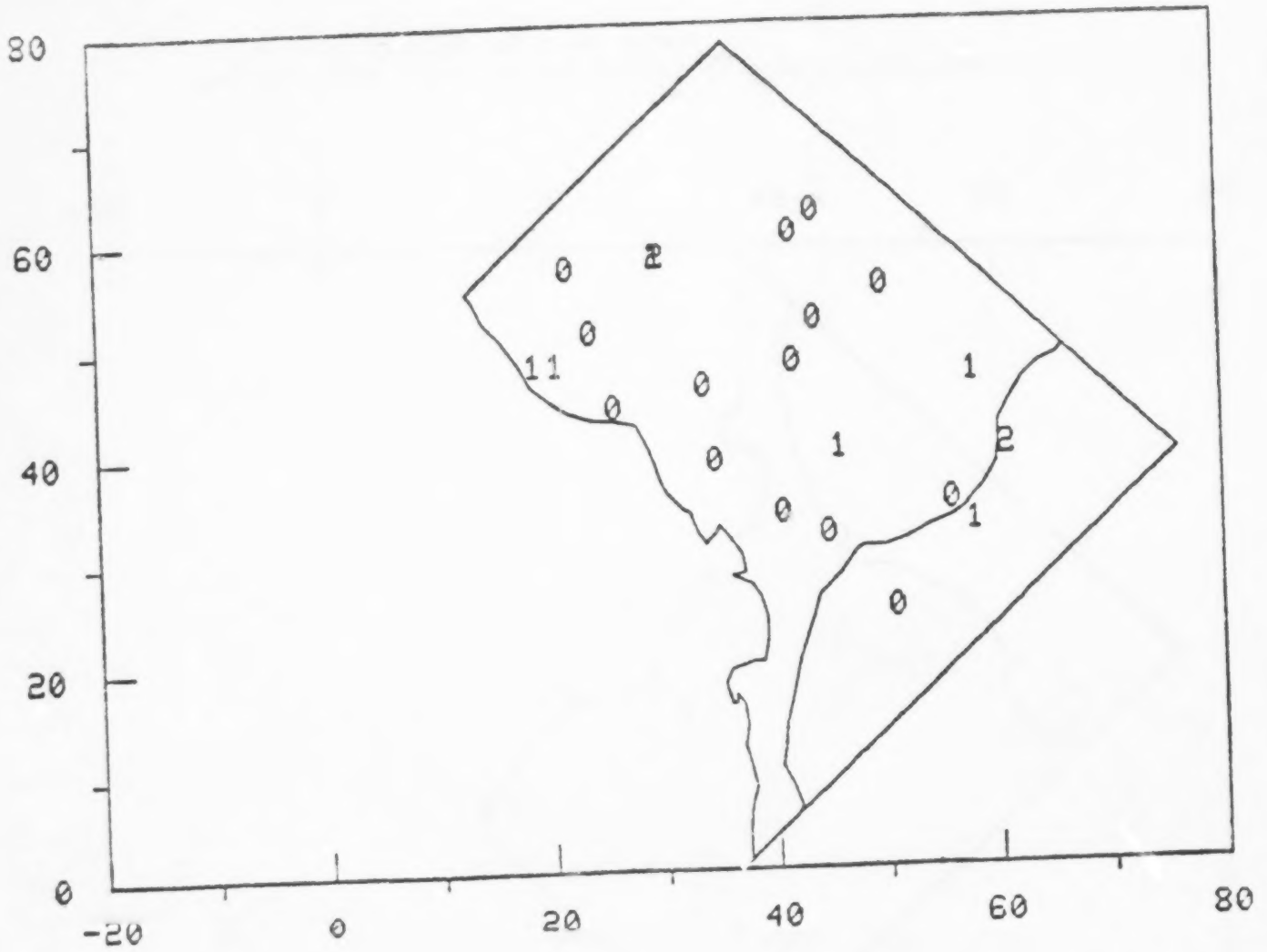
Map 19. Area-wide Distribution of Average Concentration of Lead in Street Dust



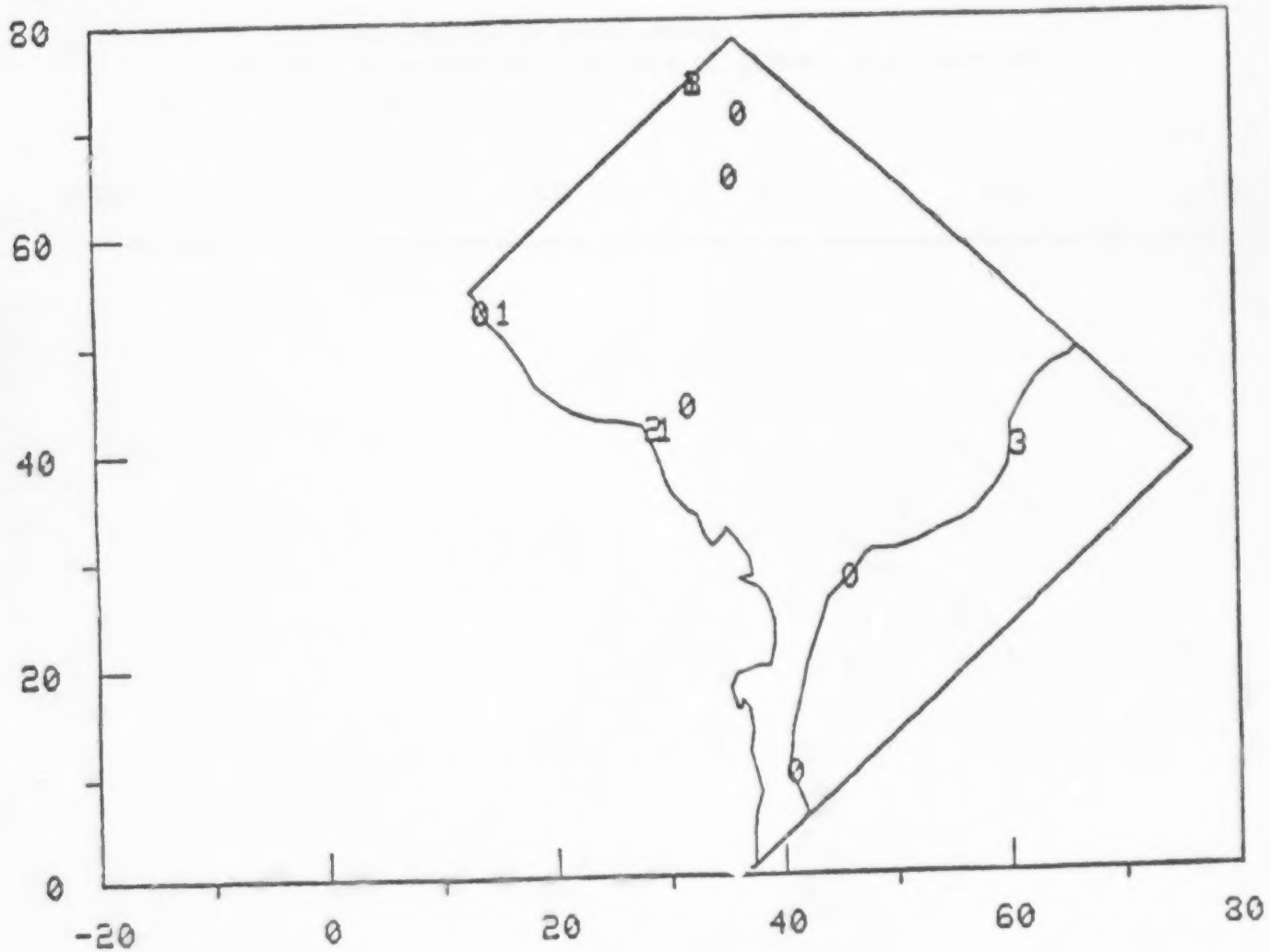
Map 20. Area-wide Distribution of Average Concentration of Lead in Bottom Sediments



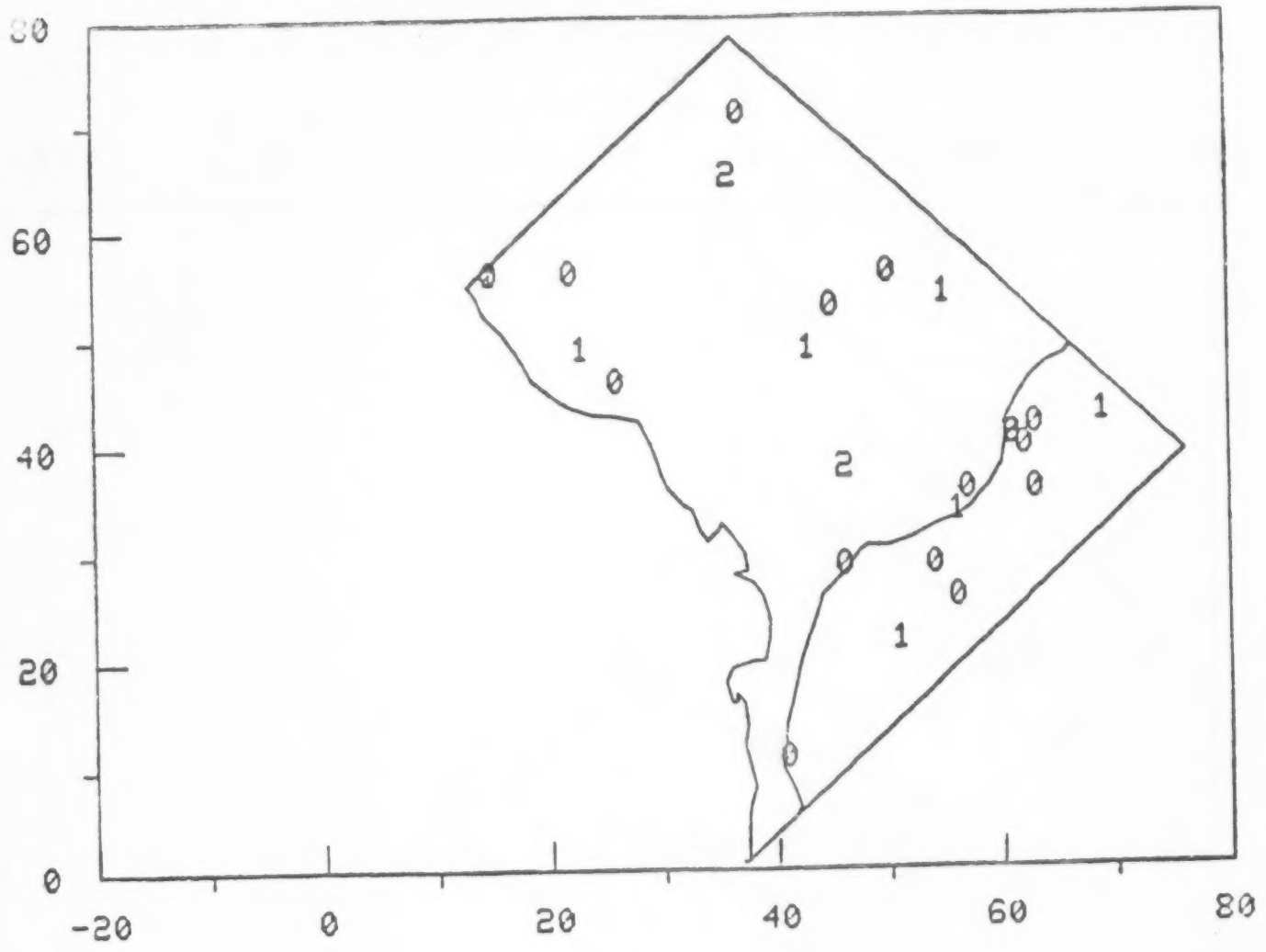
Map 21. Area-wide Distribution of Average Concentration of Cadmium in Air



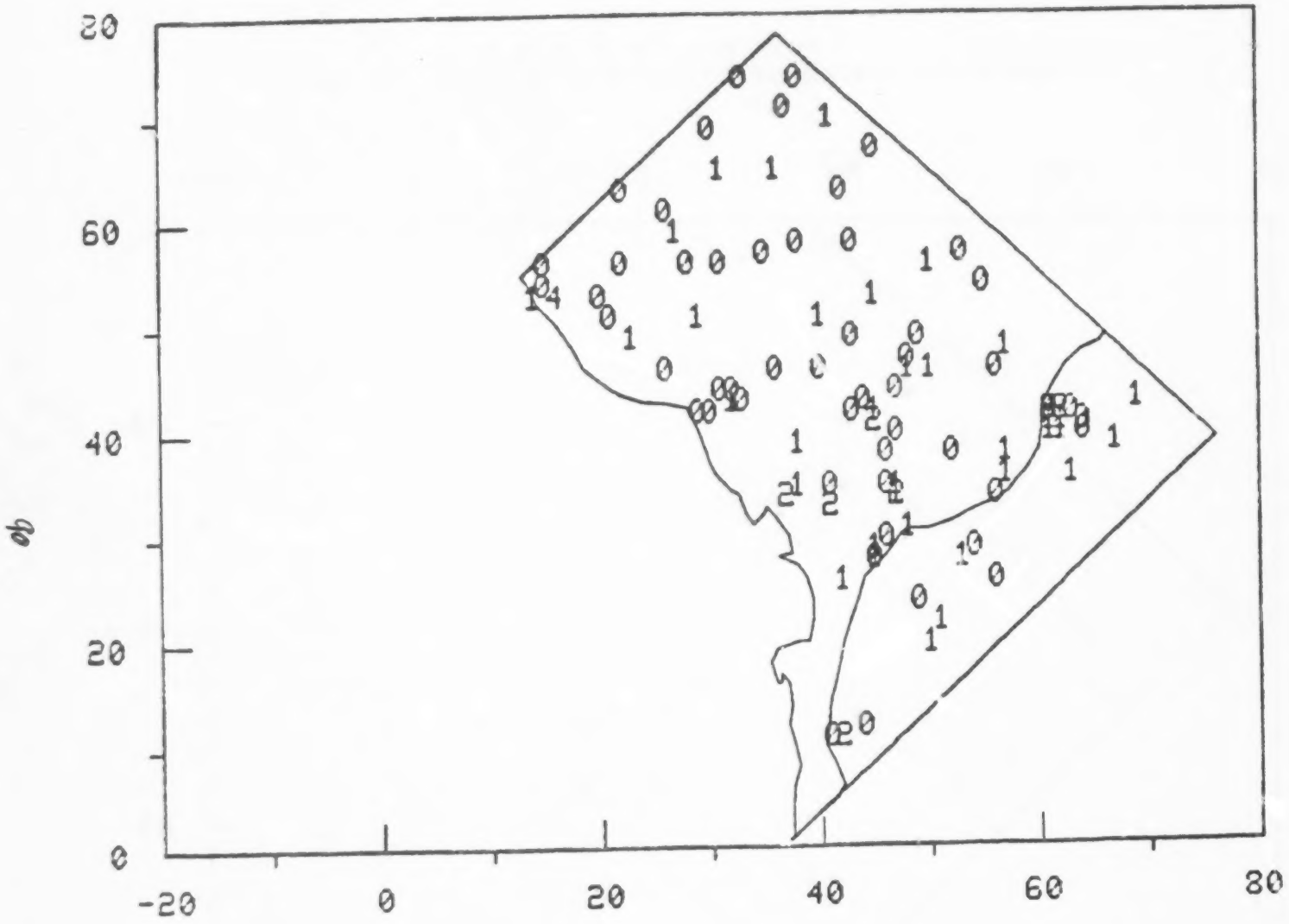
Map 22. Area-wide Distribution of Average Concentration of Cadmium in Sewer Water



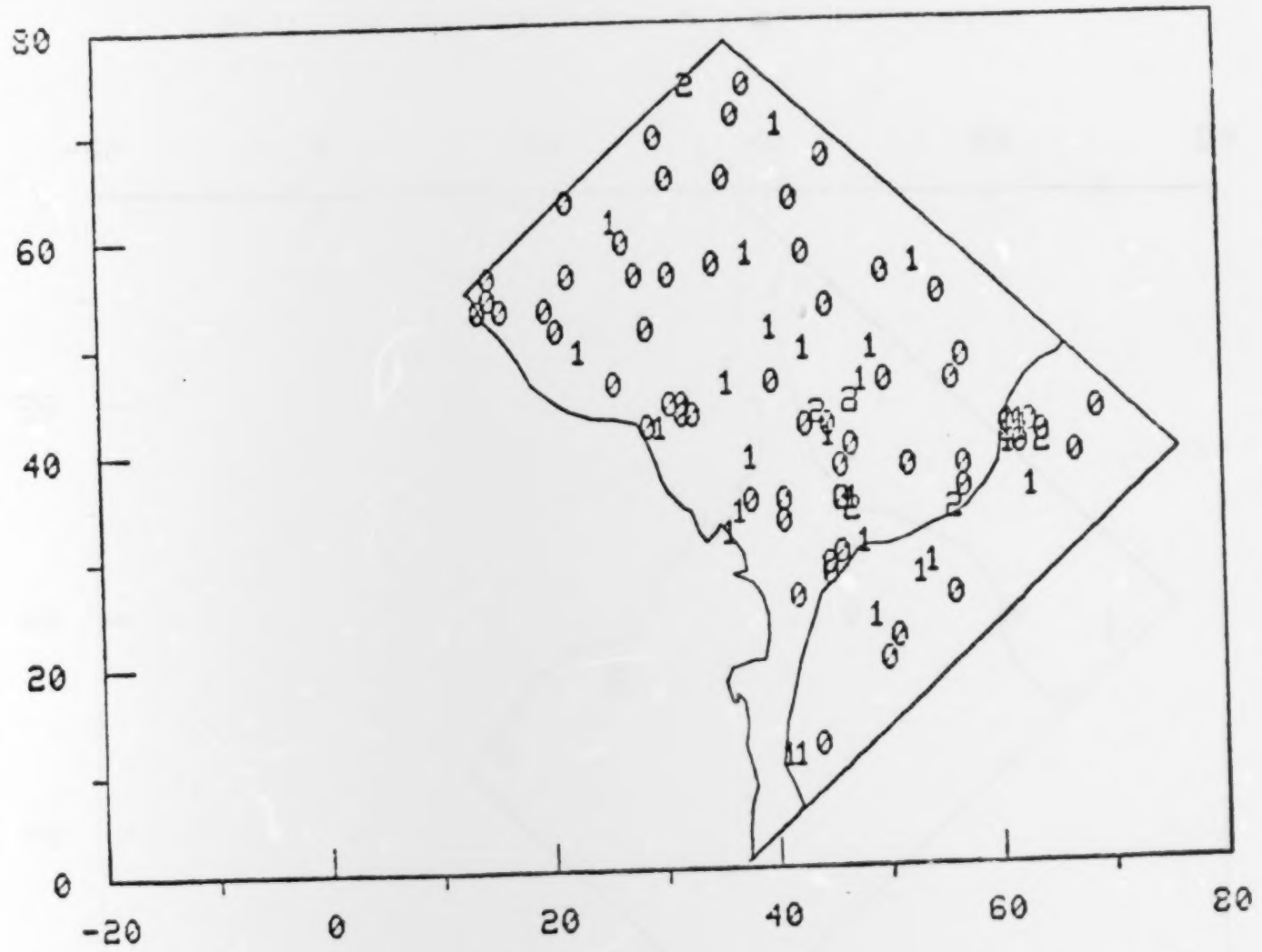
Map 23. Area-wide Distribution of Average Concentration of Cadmium in River Water



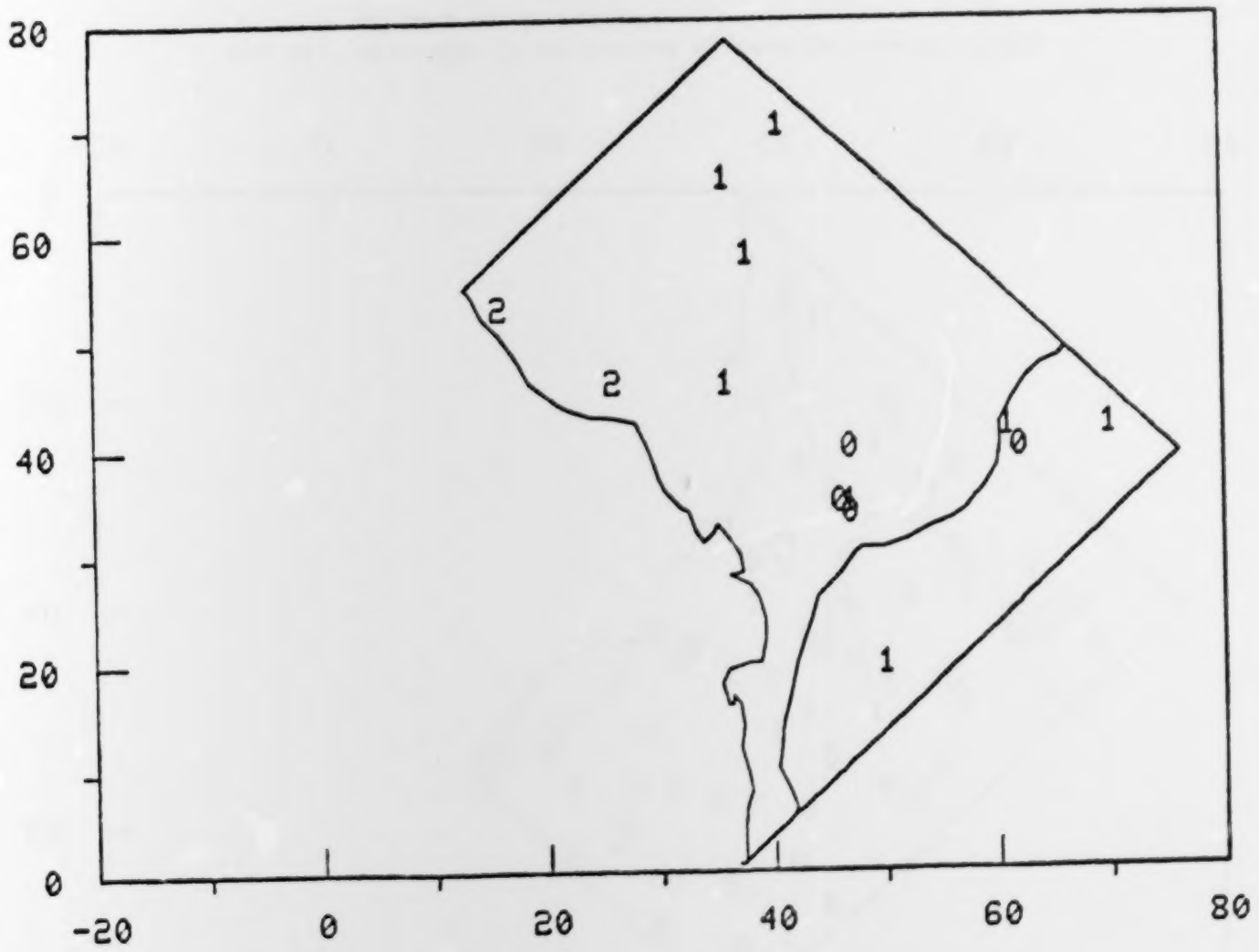
Map 24. Area-wide Distribution of Average Concentration of Cadmium in Drinking Water



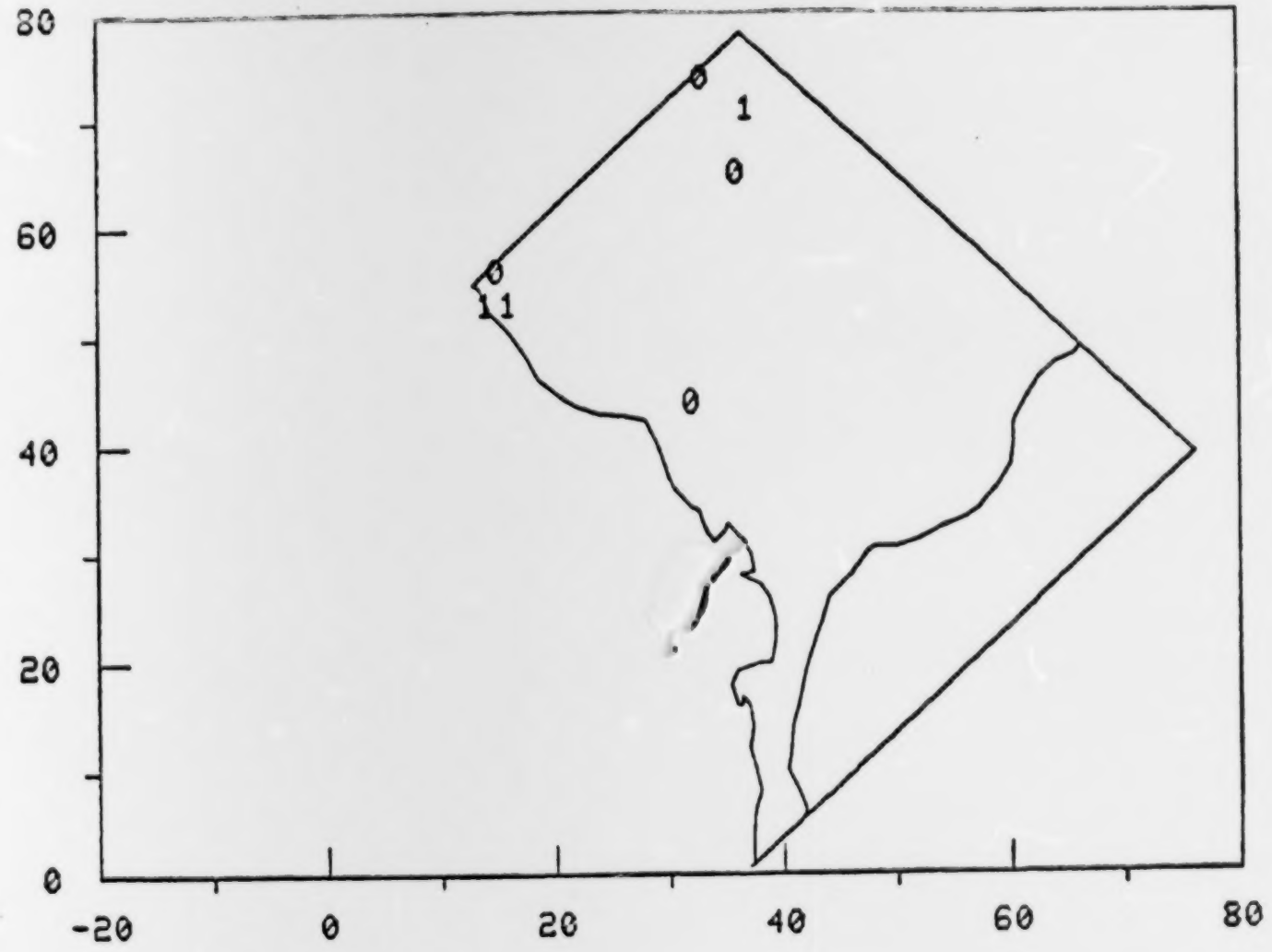
Map 25. Area-wide distribution of average concentration of cadmium in topsoil



Map 26. Area-wide Distribution of Average Concentration of Cadmium in Subsoil



Map 27. Area-wide Distribution of Average Concentration of Cadmium in Street Dust



Map 28. Area-wide Distribution of Average Concentration of Cadmium in Bottom Sediments